ENVIRONMENTAL RISKS
TO HAWAII'S PUBLIC HEALTH AND ECOSYSTEMS

Executive Summary and

Parts 1. Risks to Public Health

2. Risks to Ecosystems

3. Risks to Economic Welfare

A report of the

Hawaii Environmental Risk Ranking Study

to the

Department of Health
State of Hawaii

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EXECUTIVE SUMMARY

PREFACE

This study of Hawaii's environmental problems and management of related risks is a product of the enthusiastic participation of professionals from every part of our island society: industry, government, academia, environmental and civic organizations, and retired persons. Studying the place where one lives, using the new concept of comparative risk assessment, proved to be an attractive task. There was some money from the U.S. Environmental Protection Agency (USEPA) and the East-West Center (EWC) to cover part of the salaries for study leaders and out-of-pocket expenses. But the myriad of topics to be covered required that those individuals with specific knowledge volunteer their contributions. Many persons did so, and they are gratefully acknowledged in the listing at the end of this Executive Summary.

The Hawaii Association of Environmental Professionals (HAEP) is a relatively new professional scientific and technical group here. Its membership of about 80 is broadly representative of the environmental expertise in Hawaii. The group is a chapter of the National Association of Environmental Professionals which requires at least three years of responsible professional experience for membership. HAEP readily responded to the request from Dr. Bruce Anderson, deputy director for environmental health at the state Department of Health, to organize and carry out the study as a first step in the state's move toward Risk-Based Strategic Planning. All of the study leaders, most of the steering committee, and many of the volunteer workers are members of HAEP.

Part 1 of the study report deals with risks to human health from environmental pollution, and Part 2 covers risks to natural ecosystems from human activities. Part 3 presents case studies that demonstrate how extended benefit-cost analysis can evaluate impacts of environmental degradation on economic welfare and the quality of life. Part 4 contains technical appendices and will be published in limited number for reference. All of the backup information gathered, models used, and calculations of the study are available to interested

parties in the Hawaii Environmental Risk Ranking files at the EWC, Program on Environment.

Special recognition is appropriate for the study leaders: Randy Herold, chairman of the Steering Committee; Wayne Mitter, associate study director; Nancy Convard, coordinator of water-related problems; Sylvia Edgerton, coordinator for air pollution and toxic materials; Jim Maragos and Karin Meier, coordinators of the assessment of risks to ecosystems; and Kirk Smith, coordinator for indoor air pollution.

Peer review was provided by more than 20 colleagues from the USEPA Region IX, the local technical community, and the DOH. This final revision reflects their constructive criticisms for which the authors are grateful.

Our secretaries--Linda Shimabukuro, Joyce Kim, and Marilu Khudari--skillfully turned a jumble of manuscripts and notes into a clean report. The report had the benefit of effective editing by Helen Takeuchi and her assistant, Daniel Bauer. My thanks goes to all of these colleagues for their talents, support, and good advice.

Richard A. Carpenter
East-West Center
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ABBREVIATIONS

BOD: Biochemical Oxygen Demand

CAA: Clean Air Act
CAP: Capacity Assurance Plan
CERA: Comparative Ecological Risk Assessment
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CERCLIS: Comprehensive Environmental Response, Compensation, and Liability Information Systems
CFR: Code of Federal Regulations
Cl_2: Chlorine
CO: Carbon Monoxide
CO_2: Carbon Dioxide
COD: Chemical Oxygen Demand

DLNR: Department of Land and Natural Resources, State of Hawaii
DO: Dissolved Oxygen
DOA: Hawaii State Department of Agriculture
DOH: Hawaii State Department of Health

EDB: Ethylene Dibromide
EIS: Environmental Impact Statement
EPCRA: Emergency Planning and Community Rights Act
ETS: Environmental Tobacco Smoke
EWC: East-West Center

FDA: Food and Drug Administration
FIFRA: Federal Insecticide, Fungicide, and Rodenticide Act

H_2S: Hydrogen Sulfide
HAEP: Hawaii Association of Environmental Professionals
HBWS: Hawaii Board of Water Supply
HERR: Hawaii Environmental Risk Ranking
HRS: Hazard Ranking Scale
HSPA: Hawaii Sugar Planter's Association

IRIS: Integrated Risk Information Systems
IRP: Installation Restoration Program

LEAP: Louisiana Environmental Action Plan
LUST: Leaking Underground Storage Tank

MCL: Maximum Contaminant Level

NAAQS: National Ambient Air Quality Standards Program
NESHAPS: National Emissions Standards for Hazardous Air Pollutants
NH_3: Ammonia
NOAA: National Oceanic and Atmospheric Administration
NO_x: Nitrogen Oxide
NPL: National Priorities List

O_3: Ozone

Pb: Lead
PCE: Tetrachloroethylene

QOL: Quality of Life

RCRA: Resource Conservation and Recovery Act

SAB: Science Advisory Board
SARA: Superfund Amendments and Reauthorization Act of 1986
SOC: Synthetic Organic Chemicals
STP: Sewage Treatment Plant

TCDD: Dioxin (Tetrachlorodibenzo-p-dioxin)
TCDF: Tetrachlorodibenzofurans
TCE: Trichloroethylene
TCP: Trichloropropane
THM: Trihalomethanes
TRI: Toxic Release Inventory
TSP: Total Suspended Particulates

USCG: United States Coast Guard
USCINCPAC: United States Commander in Chief Pacific
USEPA: United States Environmental Protection Agency
USFWS: United States Fish and Wildlife Service
UST: Underground Storage Tank

VERR: Vermont Environmental Risk Ranking
VOC: Volatile Organic Compounds
VOG: Volcanic Aerosols

WERR: Washington Environmental Risk Ranking
WQ: Water Quality

EXECUTIVE SUMMARY

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Toward Risk-Based Strategic Planning

The purpose of this Hawaii Environmental Risk Ranking (HERR) study is to provide scientific information concerning the comparative risks arising from environmental pollution and degradation in Hawaii.

The relative ranking of different current risks to human health and ecosystems is the first step in a process proposed by the U.S.

Environmental Protection Agency (USEPA) to improve environmental management within federal and state governments.

The process, called Risk-Based Strategic Planning, will add broad public discussion of political, social, cultural, and economic considerations to the initial base of scientific risk ranking. Such a process can lead to a consensus on acceptability of specific risks and to a priority action agenda for:

(1) continuing successful and necessary environmental protection programs, and
(2) re-allocating money and personnel to those higher risk problems which are not getting enough attention.

The scope of this 1991-92 HERR study was constrained by the availability of data. Nevertheless, we were able to discriminate between problems of lower, medium, and higher risks. Risk assessment and comparative ranking should be a continuing process.

Future studies will benefit from additional research and monitoring that are suggested by the uncertainties reported herein. Our rankings should stimulate action toward the next step in Risk-Based Strategic Planning (i.e., public participation).

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Principal Findings

These are the principal findings of the year-long HERR study:

Lucky You Live Hawaii! Doubly so because the natural beauty and benign climate of the islands are linked with a life-supporting air and water environment that poses few current risks to our health. The state's ongoing programs to protect public health are working and must be continued.

Malama i ka 'Aina, Malama i ke Kai! - Preserve the Land and the Ocean! In contrast to the low risks to public health, valuable land and water ecosystems throughout Hawaii are at high risk of being damaged, some irreversibly, by stressors resulting from our economic and social activities. The most damaging stressors are sediment, alien species, feral animals, aquatic plant nutrients, toxic substances, and overcrowding/overuse of certain areas and resources. Degraded land and water, in turn, pose risks of substantial economic losses to our basic tourism industry and threaten our quality of life.

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What Did We Look For?

We started with a comprehensive search for hazards in pollution or a degraded environment that might affect public health or ecosystems. An initial list was circulated widely in the state to obtain public reaction and to add more environmental concerns. The resulting variety of over 70 specific problems was organized into environmental problem areas for risk assessment (Table 1).

How Did We Assess Risks to Public Health?

Risk is a useful common characteristic for comparing different health hazards. Risk expresses the likelihood (chance) that you may eat, drink, breathe, or contact some pollutant in the environment, and the severity of the illness that may result. So, we looked for plausible pathways for human exposure and estimates of the dose. Then, using USEPA data and formulas, we calculated the additional risk (over and above any routine or background level) of contracting disease from each specific environmental hazard. We recognized that there are many uncertainties due to lack of monitoring and incomplete understanding of environmental science. Hawaii's climate, lifestyle, and ethnic mix required special adjustments to mainland information before it could be applied here.

We looked at "residual risks," a term for the risks remaining after assuming adequate enforcement of existing regulations. These residual risks to public health (excluding people in the workplace), for those environmental problems we studied, are ranked and compared against one another in Table 2, with pertinent notation concerning uncertainties.

The reason for using "residual risk" comparisons for environmental management is demonstrated by the example of drinking

Table 1
Hawaii's Environmental Problem Areas

Environmental Problem Area	Specific sources of pollution, exposure pathways, and agents/stressors (expanded from the public response to the original list)
1. Industrial Wastewater Discharges to Oceans and Streams	Point source discharges Heated water Oil and grease (see also 4) Agricultural industry, feedlots Underground injection
2. Municipal Wastewater Treatment and Discharge	Method of treatment and disposal Leaks and accidental discharges of sewage Irrigation using STP effluent Coastal water quality for recreation Streams and lakes Underground injection
3. Drinking Water	Pesticides Lead Other toxics Pathogenic organisms Aquifer contamination
4. Nonpoint Sources	Agriculture Golf courses Urban runoff Construction Cesspools Feral animals (erosion)
5. Hazardous Waste	Specific chemical agents and disposal methods Hazardous waste sites - leachate Other generation or disposal sites - leachate Transportation and storage risks Waste oil drum sites
6. Accidental Releases	Hazardous and toxic materials Oil spills Geothermal, (H_2S) Industrial, military (NH_3, Cl_2) Leaking underground storage tanks
7. Pesticides	Public exposure to drift Residues in food and water (see 3) Home storage and use (see 11) Runoff (see 4)

Table 1
(continued)

Environmental Problem Area	Specific sources, exposure pathways and agents/stressors (expanded from the public response to the original list)
8. Radiation	Electromagnetic Ionizing, radon (see 11) Skin cancer (UV-B)
9. Outdoor Air Pollution	"Criteria" pollutants Toxics listed in SARA III TRI Municipal incinerators, HPOWER, Waipahu Refineries - fugitive emissions Power plants Volcano emissions Geothermal H_2S (see 6)
10. Toxic Air Pollutants	Lead, all sources Benzene, self-serve gasoline Asbestos Pathogens Cane smoke
11. Indoor Air Pollution	Tobacco smoke (passive) Household dust Pesticides Household chemicals Furniture, structures, coatings
12. Terrestrial Ecosystems	(See Table 3, p. 11)
13. Aquatic Ecosystems: fresh, marine, wetlands	(See Table 3, p. 11)
14. Quality of Life	Esthetics, natural beauty Clarity of water and air Litter Noise Crowding Cultural values Archeological sites

Table 2

Summary Comparative Ranking of Risks to Public Health from Environmental Pollution

Priority for Attention Based on Risk Ranking	Residual Risks to Public Health: General Population	Residual Risks to Public Health: Special or Smaller Populations
HIGHER Excess individual risk > 1 in 100,000 or annual excess incidence of > 10 cases in the general population, or estimated dose > reference dose in general population.	Indoor air pollutants; environmental tobacco smoke and carcinogens in consumer products. **Uncertain** because data specific to Hawaii are lacking.	Lead (extent of exposure **uncertain**) - to children from multiple sources Pesticide residues and metals in some fish eaten for subsistence (**uncertain** because of limited monitoring of fish and shell fish)
MEDIUM Individual excess risk between 1 in 100,000 and 1 in 1 million, or dose to general population > reference dose, but disease is not catastrophic.	Benzene (carcinogen)- commuters, gasoline refueling. Effect of intermittent exposures is **uncertain.**	Skin cancer from ultraviolet radiation, especially to children Carbon monoxide in poorly ventilated automobile congested areas Lead - to Big Island users of roof catchments
LOWER All health protection standards are met. Individual excess risk < 1 in 1 million.	Outdoor air pollution Criteria air pollutants Toxic air pollutants (refineries, power plants) H_2S from geothermal development Toxic and hazardous materials and wastes Accidental releases of toxics Drinking water (pesticides) Industrial wastewater discharges Municipal wastewater treatment and deep ocean outfall discharge Nonpoint source discharges to water	Volatile organic chemicals from smoldering landfills

Note: "Uncertain" means a lack of data (on exposure, impact, or likelihood of occurrence) or lack of understanding of cause-effect relationships. Available data and understanding, nevertheless, do support the stated level of risk, but the ranking may change with more information.

water. Any water resource proposed as a public drinking water supply must be approved by the Hawaii State Department of Health (DOH). Fortunately, DOH monitors both drinking water at the tap, and raw water that is, or might be, a source of drinking water. Adequate treatment must be assured for any contaminated raw water that poses significant risk. Such a program for public health protection obviously must be continued, although it should be tested for cost effectiveness. We found no instances in the state where treated drinking water failed to meet health protection standards. Thus, the "residual risk" for drinking water was given a lower comparative ranking.

It follows that until one knows the costs and effectivenss of baseline health risk management programs, one cannot use Table 2 alone to guide allocation of additional money for environmental management. However, Table 2 can be useful for judgments as to whether certain new or continuing risks are higher or lower than those risks already well under control.

What Did We Learn About Risks to Public Health?

Indoor air pollution warrants a comparatively higher ranking in Table 2, based on risk assessment data from some mainland locations. However, assessment of actual ventilation rates in Hawaii homes and indoor public gathering places, and an assessment of "typical" or "representative" concentrations of toxic chemicals in air, as well as durations and exposures, will be necessary before the higher risk ranking can be confirmed.

The indoor air example illustrates the impact which "uncertainty" can have in the process of determining environmental management policies. A modest expenditure for risk research in this case can help verify or change preliminary risk judgments and thus inform decision making about the need for regulation and/or public education on this topic.

Lead is a metal that can be ingested or inhaled from a number of sources, including house dust and dirt. Lead can get into drinking water supplied from roof catchments because lead contained in roofing materials can be leached by rain, especially the acidic rain sometimes encountered near the active volcanoes on the Big Island. Lead is believed to damage the learning ability of children. Accordingly, by recent USEPA regulation, the lead level found in children's blood which requires remedial action, has been lowered. Evidence exists that some children in Hawaii have blood lead levels exceeding this action level, so we rank risks from lead as a higher priority for government attention. More testing is under way.

Benzene is a potent cancer-causing agent found in gasoline. Gasoline is so widely shipped, stored, and used in our society that exposures of members of the public to benzene are plausible. We calculated a marginally significant excess risk of cancer due to exposures in commuting and self-service filling of automobile gas tanks. Other exposures may occur in attached garages and near leaking underground storage tanks that contain fuels comprising benzene. The effect of intermittent exposures to benzene is uncertain, however. Also, more actual exposure measurements in Hawaii are needed to confirm the "medium" ranking.

Automobile exhaust contains carbon monoxide (CO). Although outdoor air quality in Hawaii consistently meets health protection standards, the public is exposed to excessive CO levels in congested, poorly ventilated areas such as underground parking structures. People with heart disease may incur an unacceptable risk if they are exposed for an hour or more.

Termite control is essential in Hawaii. In the past, long-lasting carcinogenic pesticides in wood and in the ground around dwellings have been used extensively. Rainfall leaches these pesticides out of exposed wood or soil and flushes contaminated soil particles into runoff waters and down storm drains. Fish and shellfish can accumulate the pesticides, and when eaten, the toxic materials can affect human beings. One case example where actual data on fish are available and a plausible high-exposure pathway exists is in Manoa Stream and Ala Wai Canal. If contaminated fish from these waters are eaten often in large amounts, an unacceptable excess risk of cancer can be calculated. Occasional consumption of the same fish would not appear to pose a significant risk.

Sunlight includes ultraviolet radiation (UV-B) that causes skin cancer. Hawaii's tropical location, climate, and lifestyle invite high exposures to UV-B by our residents and visitors. A decrease in the stratospheric ozone layer in the higher latitudes is a current worldwide concern because ozone is a shield from UV-B radiation. Hawaii is not likely to get much of an increase in UV-B because of our proximity to the equator, but that geographic fact means we already have a greater intensity because of the high sun angle year-round. Children appear to be especially at risk of skin cancer in later life if they are badly sunburned. Better public education should be able to reduce this voluntarily incurred risk.

The potential hazard of exposures to electromagnetic radiation (radio and TV transmitters, high-voltage power lines, electric appliances) has come under scrutiny in the United States in recent years. Since there is as yet no evidence or theory that can be used to estimate the relationship between the strength of these sources and ill health, it is not possible to assess the risk in this study. A number of investigations are under way, however, and there is expected to be much additional information available by mid-decade.

A number of hazards, as they are now managed, were judged to pose lower residual risks to human health and, therefore, are not now a high priority for additional or special government attention. For example, deep ocean outfalls as a method of disposing of sewage treatment plant effluent appear to be working as designed. The combination of deep discharge, rapid and large dilution, prevailing winds, currents parallel to or away from the shore, and rapid die-off of pathogenic organisms in seawater (due, in part, to stronger UV-B in the tropics) works to minimize human exposure to effluent in recreation areas. Toxic chemicals are not found in Hawaii in large variety and volume. Hazardous wastes are now managed effectively within a regulated plan for collection, transportation, treatment, and for disposal on the mainland. Past improper management has created some hazardous waste sites that are now being evaluated for cleanup action, but these sites are not accessible by, and do not pose a threat to, the general public.

What We Found Out About Risks to Ecosystems

Urgent actions are needed to perpetuate Hawaii's ecosystems. Ongoing degradation of our landscape and waters from human activities now poses substantial risks to valuable natural ecosystems in Hawaii. This HERR study identifies hazards to ecosystems at specific sites that merit high priority for immediate attention by government, business, and all citizens.

We assessed all of Molokai and about one hundred specific locations from the four other major islands in this phase of the study. The landscape and waters of Hawaii were categorized into different types of ecosystems, ranging from lava tubes and alpine deserts to fishponds and fringing reefs. The geographical location of each ecosystem occurrence or site was identified. Monitoring data and research results from existing studies, plus the professional judgment of experienced environmental scientists, were used to establish a relative value and risk for each site. Four components of our value scale are biodiversity (biological resources), recreational use, economic productivity, and cultural/esthetic importance (including how native Hawaiian people use and appreciate the site).

Those ecosystem occurrences with substantial value were assessed further as to the risk, or probability, that these values and uses are now being, or will soon be, damaged as a result of our actions, lifestyles, and demands--for jobs, homes, food, business, and pleasure.

Risk was estimated by combining the likelihood of some damage-producing stress (see Table 3) and the magnitude or severity of the damage when it occurs. Some risks (e.g., the invasion of native vegetation by alien plants) are relatively certain. Others (e.g., the ability of a fishery to recover from overuse) are uncertain and require more study. For each site, we noted the degree of certainty of, or confidence in, the risk assessment.

This study is incomplete because the anticipated data and analytical assistance from state agencies have not yet been received, and only a part of the necessary funding was made available. Several ecosystem types and geographical areas have not been adequately studied. Therefore, we used expert judgment to select about one

Table 3

Stressors Impacting Ecosystem Sites

1)	Alien species	Established plants or animals introduced to the islands that were not here before. Some escape domestication or cultivation.
2)	Toxic substances	Pesticides, heavy metals, solvents, acids, oil, and grease.
3)	Nutrients/BOD	Plant nutrients including carbon, nitrogen, and phosphorous. Biological oxygen demand (BOD) for decomposing organic materials.
4)	Earth moving/development	Activities involving the clearing of vegetation, removal of soil, or changes in runoff patterns.
5)	Erosion/sedimentation	Soil disturbance by animals or mechanical means and displacement by wind or rain. Sediment delivery.
6)	Water diversion	Water resources development, channelization, dams and reservoirs, wells.
7)	Noise/light	Unnatural intensity, timing or place of occurrence.
8)	Heat	Heated water discharges or other significant change in temperature of an ecosystem.
9)	Human crowding	Trampling of plants, soil compaction, litter, disruption, turbidity, crowded beaches and parks, overfishing.
10)	Global climate change	Warming and consequent changes in rainfall patterns, sea level rise. Ozone depletion leading to increased UV-B.
11)	Fire	Unnatural occurrence of fire in vegetation due to human activity, accidental or purposeful.
12)	Explosives	Civilian construction or military activities.

hundred (out of several hundred) valuable sites throughout the state for immediate risk ranking, and chose to complete the assessment of all sites only on Molokai, as a pilot study. The results are, nevertheless, useful and instructive.

Our study shows a clear pattern as presented in Table 4 and described as follows. Most of Hawaii's high-value sites are in the coastal area--wetlands, fish ponds, streams, estuaries, coastlines, and reefs. Aquatic ecosystems are at a higher risk from these stressors:

- alien species of plants and animals;
- sediment delivered from upland soil erosion due to feral animals, agricultural practices, and development activities;
- plant nutrients that cause growth of algae and seaweed; and
- human crowding and overuse.

Some of the high value upland terrestrial ecosystem sites such as grass and shrublands, forests, and montane areas are at higher risk because of fire hazard as well as soil erosion, alien species, and human crowding.

The findings illustrated in Table 4 are the results of an intensive, one-day workshop at which a panel of environmental experts ranked sites thought to be of high value and at risk. Due to time constraints, only approximately 20 sites on each of the main Hawaiian islands, other than Molokai, were considered, and efforts were made to represent as many different ecosystem **types** as possible. Therefore, many other important sites were not addressed. However, it is believed that these preliminary priority sites will remain in the higher risk category as the HERR study is continued and becomes more comprehensive.

One of the most significant threats to Hawaii's native plants, birds, and other animals is the destructive effect of alien species, or those introduced to the islands by humans. Hawaii's native plants, birds, insects, and animals evolved on the islands without natural enemies, over time losing whatever defenses the species originally had. When humans first came to the islands, the introduction of

Table 4
Highly Valuable Ecosystem Sites in Hawaii That Are at High Risk

Sites	Most Likely and Damaging Stressors - Higher Risks: Soil Erosion Sedimen-tation	Alien Species	Earth-moving Develop-ment	Human Crowding & Overuse	Plant Nutrients
<u>Aquatic Ecosystems</u>					
Hawaii					
Coconut Island				x	x
Honaunau coastline	x		x	x	
Hamakua stream		x	x		
Ka Lae anchialine pools	x	x			x
Kauai					
Hanalei stream	x	x			
Menehune (Alekoko) fishpond	x	x			
Lanai					
Manele-Hulapoe reef	x			x	
Shipwreck Beach	x		x	x	
Maui					
Auau Channel offshore	x			x	
Maalaea Bay nearshore	x				x
Molokini reef				x	
Honolua Bay reef	x			x	
Puu Olai-North reef	x			x	
Makamakaole stream	x	x			
Hanawi stream	x	x			
Maalaea coastline	x			x	

Table 4 (continued)

Sites	Most Likely and Damaging Stressors - Higher Risks				
	Soil Erosion Sedimen-tation	Alien Species	Earth-moving Develop-ment	Human Crowding & Overuse	Plant Nutrients
Molokai					
Kapukalaulua fishpond	x		x		x
Kipapa fishpond	x		x	x	
Halawa stream	x	x			
Kawela streams	x	x			
Halawa Bay estuary	x	x		x	
Ooia Pond to Kaunakakai coastline	x		x	x	
Kaunakakai to Kapukalaulua coastline	x	x	x		
Oahu					
Kaneohe Bay Reefs		x		x	x
Kahana streams	x	x			
Kahana estuary	x	x			
Nuupia fishponds	x	x			
Moku Auea (Goat Island)		x		x	
Hanauma Bay reef	x	x		x	

Table 4 (continued)

Sites	Most Likely and Damaging Stressors - Higher Risks				
	Soil Erosion Sedimentation	Alien Species	Earthmoving Development	Human Crowding & Overuse	Fire
<u>**Terrestrial Ecosystems**</u>					
Hawaii					
Wailoa wetland		x		x	
Windward Hamakua forest	x	x			
Kapapala Kau dry forest	x	x			
Hualalai montane forest		x	x		x
Mauna Kea-Mauna Loa subalpine		x	x		x
Kauai					
Mana floodplains	x	x			
Hanalei wetland	x	x	x		
Waimea/Olokele Canyon	x	x			x
Kokee/Puu Kapele	x	x			
Lanai					
Kanepuu low dry/mesic forest	x	x			x
Lanaihale montane wet shrubland	x	x		x	
Maui					
Kealia Pond/Maalae mud flats	x	x			
Waihee; (Waiehu) wetland	x	x	x		
W. Maui pili grassland	x	x			x
W. Maui low dry shrubland	x	x			x
Haleakala montane wet shrubland	x	x			

Table 4 (continued)

Sites	Most Likely and Damaging Stressors - Higher Risks				
	Soil Erosion Sedimentation	Alien Species	Earthmoving Development	Human Crowding & Overuse	Fire
Molokai					
Oalapue wetland	x	x	x		
S. Molokai mudflats	x	x	x		
Ilio Point to Puu Koai coastline	x	x	x		
Ka Le Mau to Makalii coastline		x		x	x
Moomomi coastal shrubland	x	x			x
Hakaaano - coastal forest	x	x			x
Kikipua Point - coastal forest	x	x			x
Kamiloloa lowland dry shrubland		x	x		x
Wailau Trail low dry forest	x	x	x		
Puu Ohelo cliffs and valley	x	x			
Kalaupapa Caves lava tube		x	x	x	
Oahu					
Kahuku-West coastline			x	x	
Kahuku wetlands	x	x	x		
Kahuku coastal herblands	x	x		x	
Kahuku coastal shrubland	x	x		x	
Kaena Point coastal shrublands	x	x		x	
Waianae Mountains low dry/mesic forest	x	x			x
S. Waianae Summit low wet forest	x	x			x
Koolau Summit low wet forest	x	x		x	
Kahoolawe	x	x			

plants and animals took a toll on the sensitive native ecosystems. Domestic pigs escaped into the forests and destroyed many acres through rooting and eating. New species of plants quickly moved in to overtake the Hawaiian species. Today, as many as 35 new alien species have been known to invade our islands in a single year, and the threat of more serious invasions, such as the brown tree snake, is alarming.

The marine ecosystems are in danger of alien species proliferation also. Fish and seaweed have been introduced into our waters causing many problems that we are just beginning to comprehend.

Nonpoint source pollution is a widespread and significant hazard in Hawaii. Unlike pollution from industrial and sewage treatment plants, nonpoint source pollution comes from many diffuse sources. Nonpoint pollution is caused by rainfall moving over and through the ground. As the runoff moves, it picks up and carries natural and man-made pollutants, finally depositing them into streams, wetlands, and coastal waters. These pollutants include fertilizers, herbicides, and insecticides from agricultural and residential areas, and golf courses; oil, grease, and toxic chemicals from urban runoff; sediment from roadbuilding and construction sites, crops, and eroding stream banks; and from feral animal disturbances.

Feral animals are domestic animals which have been released into the wild, causing extreme damage to our native forests. Wild goats and pigs eat vegetation and root in sensitive forest areas. Once the soil-binding plants are gone, rainfall erodes the soil and carries it into streams and the ocean. Soil erosion/sedimentation is a major stressor at about 65% of the sites studied.

Maui and Oahu have the most sites at higher risk, primarily because of their greater population density. Human crowding is a major hazard at almost one-half of the one hundred sites assessed statewide.

In summary, Part 2 of this Hawaii Environmental Risk Ranking report locates valuable ecosystems, and identifies specific stressors resulting from our human activities that are jeopardizing the future integrity, use, and productivity of those ecosystems.

Risks to Economic Welfare

The close link between a healthy environment and continued success as a tourist designation is obvious. Quantifying the economic damage from environmental degradation is difficult, but the results of a pilot study as a part of this Hawaii Environmental Risk Ranking effort demonstrate methods for such quantification. More research and survey work are warranted to demonstrate how money spent now on environmental protection can also protect the tourism industry.

Part 3 of this report introduces techniques for evaluating risks to economic welfare that result from ecosystem degradation. It demonstrates methods and suggests data gathering requirements for assessing these risks. Case studies of recent and ongoing degradation at Hawaii ecosystem sites include:

Pearl Harbor: management alternatives for erosion, sediment control, and wildlife habitat. Benefits and costs are compared for both downstream control (dredging) and upstream control (minimizing erosion/sediment delivery).

Lahaina, West Maui: economic impacts of algal blooms that reduce water clarity and thus adversely affect snorkeling and diving. Damage costs to the hotel and ocean recreation industries are estimated. A preliminary scope of studies needed for a definitive benefit/cost analysis is presented.

Kaneohe Bay, Oahu: benefits/costs of ecosystem management alternatives. Benefit/cost data are presented for scenarios that vary from "minimal impact" to "no action," which would allow the present increasing trend of damaging activities to continue. A spectrum of stressors is identified, as are specific commercial and recreational values associated with the bay. A recommended plan of the Kaneohe Bay Task Force is a compromise that balances recreational use with protection of the fishery.

Hanauma Bay, Oahu: benefits/costs of recent management decisions. Hanauma Bay is at great risk from pollution and overcrowding. This unique underwater park is continually losing coral, showing a shift in populations of colorful reef fish, and simply becoming less attractive to visitors. Recent changes in tour bus rules, parking, and park hours reduced visitor numbers by 32% from 1989 to 1991. These changes have substantial costs, but the priceless asset of Hanauma's natural beauty may yet be preserved if necessary restrictions are imposed. Substantial tour revenue losses result from reducing "intensity of use," but the very existence of this unique ecosystem is at risk.

Oil Spill Pollution Risk: benefits/costs of spill prevention alternatives. Small spills require, and are getting, management attention. The economic welfare risk to Hawaii of a large oil spill is a function of the cost of such a spill and its probability of occurrence. The damage costs of a very large spill could be catastrophic. The probability of such spill is small, but costs of response to such spill are such that cooperative efforts that include federal government and industry capabilities must be part of any response plan.

Kawai Nui Marsh, Oahu: Costs and benefits of ecosystem management for multiple uses illustrate tradeoffs between flood control and recreation, esthetic and educational values.

The Next Steps Toward Risk-Based Strategic Planning

Risk-Based Strategic Planning combines information and value judgments from science, economics, and the public to improve environmental management.

Details for implementation of Risk-Based Strategic Planning at the state level are just now evolving in Hawaii. Three stages are envisioned.

1. Ranking of Environmental Risks--to be based on best available scientific information as presented in this report and subsequent activities.
2. Public Participation--to refine the ranking and determine "acceptability" of risks, based on quality of life issues, cultural values, economic welfare effects, and environmental management costs.
3. Prioritization of Effort and Funding for Environmental Management--within the programs of the government of Hawaii.

In preparing this report, we are aware of the difficulty in communicating information about risks because of differences in risk perception. Acceptability of a risk depends, to a large extent, on the degree of control that an individual has over exposure; an involuntary risk is less acceptable than a voluntary risk of the same magnitude. The distribution of risks and benefits also effects acceptability; if the person taking the risk does not get the benefits, he or she is less willing to accept the situation. The tradeoffs should be the result of an informed, participative, and democratic political process.

We believe that the methodology and procedures we have begun should be institutionalized in the state government. Risk ranking should be repeated and extended every few years as a continuous input to decision making.

Important data for risk assessment are not yet available. Monitoring and research cost money and so must be planned to get the most valuable information for risk management at the least expense. Data needs for evaluation of risks to public health include:

- concentrations of toxic substances in the air in a variety of indoor living areas;
- concentration of toxic substances in bottom sediments of embayments, streams, and coastal waters, and in associated plants and animals that may be used as food;
- sources, rates of movement, and concentrations of sediment and absorbed or dissolved toxic substances in major watersheds--in order to better understand nonpoint source pollution;
- transport and fate of liquids injected underground in wells or by infiltration;
- a useful indicator (organism) of the health hazard in sewage contaminated recreational waters;
- ecosystem monitoring on land and in coastal waters to document trends and identify restoration needs; and

- actual exposure of special populations statewide to hazards such as waste dumps, enclosed parking structures, and contaminated fish or shellfish.

Additional data needs for evaluation of risks to ecosystems include:

- ranking of all valuable sites on the other major inhabited islands (as has been done for Molokai);
- additional measurements of the condition of lowland terrestrial ecosystems; and
- development of a geographical information system to analyze the data base of ecosystem sites, their values and response to stressors.

Risks Not Assessed

Some risks could not be assessed and should be covered in future work as additional information becomes available. At present, however, using even the most extreme adverse values plausible for the scenarios involved does not indicate that any of these risks would fall in the higher priority level. The following hazards are not assessed in this study.

- Smoke from cane fires. No exposure data for the general public are yet available from a study that is currently under way.
- Fish and shellfish that may be contaminated with heavy metals or toxic chemicals in sediments. No data are available except for pesticides and metals in fish from Manoa Stream and the Ala Wai Canal and a few samples from Kaneohe Bay. Pearl Harbor sediments may be investigated as part of the Superfund site work there.
- Electromagnetic radiation from appliances, power lines, and transmitters. This possible hazard is not regulated for public exposure by the state or USEPA. No cause-effect

relationship for human health is accepted as yet in the scientific community.

- Lowland and coastal terrestrial ecosystems. Surveys and inventories of the value of ecosystem occurrences are inadequate for stressor-impact analysis. Only some rare species have been identified.
- Drinking water source contaminants identified since 31 January 1991. Also, the possible migration to drinking water sources of contaminants known to be in soils or in discharges to underground injection wells has not been considered because of lack of knowledge about the transport and fate of these compounds.
- Underground storage tanks. When the risks in this study were being assessed and compared (up to early 1992) the data on USTs were not available. DOH is likely to assemble the necessary information before Risk Based Strategic Planning is implemented, and thus risks from USTs can be a part of those deliberations.
- Global warming. The probability is high that the average temperature of the earth will rise significantly by the middle of the twenty-first century. There is great uncertainty, however, as to the consequences for weather and climate in any particular locality, especially tropical islands. One consequence important to Hawaii would be sea-level rise due to the expansion of the global oceans. Shorelines would change and some ecosystem occurrences would be replaced by others. Global warming may increase the frequency and severity of hurricanes. The rate of sea-level rise will be slow so that adaptation of plants and animals may take place and ecological integrity of the Hawaiian islands may continue. It is likely to be a long time before consequences of global warming would be substantial. Furthermore, there is considerable uncertainty as to what these consequences would be. Accordingly, assessing and ranking this risk is not practical at this time.

- Chemical sensitivities. This study recognizes that certain environmental factors perceived by some persons as having adverse health effects cannot be assessed, because the factors have no expression in terms of scientific theory or replicable empirical data. For example, "multiple chemical sensitivity" is a complaint that trace amounts of certain chemicals make certain persons ill. These victims deserve sympathy and symptoms of illness can be verified. No explanatory paradigm or cause-effect relationship is available, however, that meets the requirements of science and logic (i.e., no falsifiable hypothesis is stated). Another example is the claim of human health damage from electromagnetic radiation due to high voltage lines, electric appliances, or radio/TV transmitters. Other similar perceived threats are disease from "viable, nonculturable pathogenic organisms" and the combination of stresses in urban living. For risk assessment, the evidence in support of any environmental hazard must be quantifiable and relevant. Extraordinary claims demand extraordinary evidence, and the burden of proof rests on the claimant, since it is logically impossible to prove a negative.
- Extrapolation from specific sites to the entire Hawaii population. We realize that the risks calculated for specific examples (such as the congested parking structure at Ala Moana Shopping Center) should be extrapolated to the general population state-wide. Data to do so, however, are not available and estimates (such as exposures in similar parking structures elsewhere in the state) would be mere conjecture. This study points the way for the next round of comparative risk assessment to complete the investigation of these possible health hazards that we have identified.

<u>Quality of Life (QOL)</u>

Good health and being surrounded by natural ecosystems that are intact contribute significantly to any definition of a high quality of life. Therefore, these two major topics of this largely biogeophysical scientific study provide valuable measures of Hawaii's quality of life. There is more to the definition of QOL, however--employment, family relationships, and social security, for instance. Even more subjective components of QOL are religion, esthetics, and cultural assets. For QOL, it is (properly) what cannot be counted that actually counts the most.

The HERR study touches on a few of these other aspects of QOL--for example, crowding that adversely impacts vulnerable ecosystems, cultural uses that add to the value of a site, or the perception of risk from trace-contaminated drinking water. Litter and hydrogen sulfide odors are nuisances but usually are not risks to health or ecosystems. Noise may be both. QOL in its entirety is far more than these environmental components. No comprehensive public opinion poll of what QOL means in cosmopolitan Hawaii has ever been performed. This study has no data or documentation that would permit a ranking of risks from environmental degradation on the basis of their impact on QOL. To repeat, health and intact ecosystems, *per se*, are important, but they are only two components of this complex concept.

Costs of Environmental Management in Hawaii

Risk-Based Strategic Planning for environmental protection is big business. While it is not the purpose of the Hawaii Environmental Risk Ranking study to critique past decisions, costs to society of hundreds of millions of dollars have resulted from projects that were implemented without complete risk-cost-benefit analysis, including:

- requirements for low sulfur fuel at the Kahe Power Plant;
- removal of asbestos from public buildings; and
- advanced levels of treatment of municipal sewage at certain treatment plants on Oahu.

DOH is annually spending over $5 million of state funds and almost $4 million of federal funds for environmental management. Spending by the state departments of Land and Natural Resources (DLNR) and Agriculture (DOA) for related health/ecosystem purposes is on the same order of magnitude.

The Nature Conservancy of Hawaii is spending $3 million this year for ecosystem research/management.

The City and County of Honolulu is spending about $30 million this year for wastewater treatment operations and maintenance alone. Its capital improvements budget this year for wastewater treatment is more than $100 million.

Although no specific figures have been assembled, a reasonable estimate of current expenditures by federal agencies for environmental management within Hawaii, for a combination of human health and ecosystem reasons, is well in excess of $50 million annually. Most of this currently is for study and remediation of former hazardous waste sites, primarily sites of U.S. Department of Defense activities.

When private-sector expenditures to comply with environmental regulations and their interpretation are also considered, the opportunities are substantial for more effective environmental management through use of risk-based strategic planning in the economy of Hawaii.

PART 1

RISKS TO PUBLIC HEALTH

PART 1

CONTENTS

TABLES

No.

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PART 1. RISKS TO PUBLIC HEALTH

INTRODUCTION

PURPOSE OF COMPARATIVE RISK RANKING AND RISK-BASED STRATEGIC PLANNING

The State of Hawaii is beginning Risk-Based Strategic Planning as a process for setting priorities among its programs to manage the natural environment. The first step in that process involves risk assessment, risk comparisons, and risk ranking. A grant from the U.S. Environmental Protection Agency, managed by the State Department of Health, is assisting that first step through the Hawaii Environmental Risk Ranking study (HERR).

The purpose of RISK-BASED STRATEGIC PLANNING is to increase the effectiveness of government activities in reducing risks from environmental degradation. The USEPA intends that the Risk-Based Strategic Planning process be introduced at the federal and state levels. The Administrator of the USEPA, William Reilly, has best expressed this concept in a September 1990 speech (to the National Press Club) wherein he said, "Whereas much of US environmental management policy has hereto been based on Ready, Shoot, Aim, we plan to change that to Ready, Aim, Shoot."

ORIGINS, SCOPE, AND CONSTRAINTS OF THE HERR STUDY

The HERR study is a technical review and risk assessment of environmental problems in Hawaii culminating in a comparative ranking of risks to human health and ecosystems inherent in those environmental problems. The study grew out of an idea proposed to the Hawaii Association of Environmental Professionals (HAEP) early in 1991 by the State Department of Health. HAEP, the Hawaii chapter of the National Association of Environmental Professionals, selected a steering committee and a study director, set scope and definitions as shown in Table 1-1 and called for volunteers from throughout the local professional community. Government expertise was mobilized by the Office of the Governor and coordinated by the Department of Health.

Table 1-1

Scope and Definitions in Environmental Risk Assessment

The scope of the Hawaii Environmental Risk Ranking study is limited as follows:

- Only available, existing data were used. No new measurements were taken. The risk assessments were completed early in 1992 although some revisions were made as a result of reviews of a draft report.
- The time frame was from the present to about 5 years into the future.
- Health risk assessments concerned exposures of members of the public (i.e., public health), not exposures of workers (i.e., not occupational health).
- The comparative assessments are of "residual risk," the risk remaining after assuming all existing regulations are met and all currently effective health protection programs are confirmed.
- Risk assessments deal with technological hazards (i.e., of anthropogenic origin) not natural disasters.
- Only risks to natural ecosystems were evaluated (to highly modified not urban or agricultural areas).
- The risks of depletion of non-renewable resources were not addressed.

Definitions of Terms Frequently Used in Risk Assessment

- Environmental Risk Assessment evaluates actual damage and predicts potential damage to a) human health, from exposure to environmental hazards, and b) ecosystems, from environmental degradation due to human activities.
- Risk is the probability of damage to human health or to an ecosystem (from a hazard to the environment). Risk is a function of the likelihood that an adverse impact will occur, and the severity of the consequences. Health risks are often expressed as additional risk of death or disease from a particular hazard (e.g., one in a million).
- Hazard is the source of harm, a danger or peril (e.g., pesticide applications, dredging).
- Stressors are consequences of human activity that can damage health or ecosystems (e.g., release of toxic materials, introduction of alien species).
- Probability deals with the distribution of possible values for some measurement, recognizing that the mean or average value may not adequately represent the range.
- De minimus: "the law does not deal with trivialities." An excess risk (beyond the natural background risk) to an individual of contracting a disease from a lifetime of exposure to environmental causes is said to be "de minimus" if the risk is less than one in a million, or 10^{-6}. This is about the chance of an individual being struck by lightning on the mainland United States during his lifetime.
- Uncertainty is an expression of indefiniteness. It may arise because of lack of information (e.g., inadequate monitoring), or understanding (e.g., unknown cause-effect relationship).

In the United States, the public, the Congress, and the EPA are greatly concerned with cancer. It is a dread disease because of the lack of curative treatment, the long latency period, the painful and debilitating final stages, and the fact that about 1 in 4 deaths are due to cancer. Environmental health risk assessment is mostly about chemical carcinogens (both natural and synthetic) that impact the human body through ingestion, inhalation or skin absorption. Any comparative risk assessment thus appears distorted in emphasis by the dominance of cancer as a hazard and chemicals as a cause of cancer. There is a scientific controvery as to whether current levels of synthetic pesticide residues in food or water may be less of a cancer hazard than background levels of natural substances (Ames and Magaw 1987). Environmental sources (outside the workplace) of synthetic carcinogens represent only a few percent of all of the causes of cancer (Doll and Peto 1981).

Since 1950, substantial research to understand cancer has resulted in hundreds of chemical compounds being tested in animals. Results of these tests are the basis for most quantitative environmental health risk assessment. This basis is now increasingly criticized in the scientific community and may be modified in the future. For example, should risks from short, intermittent, low-level human exposures be predicted from animal tests of continuing, life-long, high-level exposures? Nevertheless, the Hawaii Environmental Risk Ranking study accepts and uses the current USEPA process for assessing health risks from chemical carcinogens as the best that is now available.

<u>Non</u>-cancer diseases that may be associated with environmental pollution or degradation have received much less attention in risk assessment. The ranges of health damage, treatment effectiveness, and recovery from these diseases are quite wide and varied. It is difficult to separate environmental sources and exposure pathways for these diseases from other causes such as heredity, lifestyle, hygiene, and behavior. The use of reference doses for non-cancer disease agents is subject to the same constraints as potency factors for carcinogens, since the reference doses are based largely on animal tests.

It was not within the scope of the HERR study to question risk levels used in setting federal and state ambient environmental standards and emission standards to protect public health. Accordingly the HERR study examined "residual risks." Thus any risks which resulted from emissions or ambient conditions that met State or USEPA standards were automatically accorded a comparatively lower risk ranking. Otherwise the standards themselves would be immediately called into question. And yet in terms of objective, absolute risk assessment, these health protection standards themselves range over 100-fold in individual lifetime risks of contracting disease (from 10^{-6} to 10^{-4}). This is because different standards have been based on different considerations of risk management, safety factors, and health endpoints. For example, some maximum contaminant levels (MCLs) are set at the detection threshold, which may change with improvements in analytical techniques.

For ecosystems, no widely accepted risk assessment method exists. The innovative HERR approach is based on the ecological community-site-stressor concept developed by the EPA Science Advisory Board and Oak Ridge National Laboratory. The entity at risk is not a single person (as in human health) but is a community of organisms and their surroundings. The endpoint is not disease or death but is some status of ecosystem structure and function that prevents a site from continuing intact, or progressing in a natural, integrated way.

Natural disasters, such as tsunami and hurricanes were not addressed except as they might increase the risks from technological hazards. The risks of depletion of non-renewable natural resources (e.g., nearshore sand, basal water, stone) was not assessed but overuse of renewable resources is included.

Despite these constraints, environmental risk assessment is practical and useful. It exposes hidden assumptions and presents uncertainties clearly. It is the best way available of comparing apples and oranges (i.e., environmental risks of widely differing character).

THE NEXT STEPS TOWARD RISK-BASED STRATEGIC PLANNING

Risk-Based Strategic Planning combines information and value judgments from science, economics, and the public to improve environmental management.

Details for implementation of Risk-Based Strategic Planning at the state level are just now evolving in Hawaii. Three stages are envisioned.

1. Comparative ranking of Environmental Risks--to be based on the best available scientific information and judgment of scientists, as presented in this report, and on subsequent risk assessment activities by state agencies.
2. Public Participation--to refine risk rankings and help determine "acceptability" of risks, based on quality of life issues, cultural values, economic welfare effects, and environmental management costs.
3. Prioritization of Effort and Funding for Environmental Management--within the programs of the government of Hawaii.

In preparing this report, we are aware of the difficulty which can be expected in communicating information about risks because of the different ways in which individuals perceive risk. Acceptability of a risk depends, to a large extent, on the degree of control that an individual has over exposure; an involuntary risk is less acceptable than a voluntary risk of the same magnitude. The distribution of risks and benefits also affects acceptability; if the person taking the risk does not get the benefits, he or she is less willing to accept the situation. Decisions with respect to acceptability of environmental risks should be the result of an informed, participative, and democratic political process.

We believe that the methodology and procedures we have begun should be institutionalized in the state government. Risk ranking should be repeated and extended every few years as a continuous input to decision making.

Much important data for risk assessment are not yet available. Monitoring and research cost money and so must be planned to get the most valuable information for risk management at the least expense.

As Risk-Based Strategic Planning is implemented in Hawaii, this HERR report should be considered the first step of a continuing comprehensive analysis of the ever-changing state of the environment. Many data are as yet inadequate for risk assessment, monitoring of effects is just beginning in some problem areas, and new hazards are being identified. Nevertheless, the comparative risk rankings in this HERR report comprise the first systematic comprehensive examination of risks inherent in the State's environmental problems. They should be useful as the first step in the process of reallocating budgets, personnel, and management attention for more effective government programs.

METHOD OF THE STUDY

Risk assessment is organized common sense. First, hazards are identified. What can go wrong? The term "environmental problem areas" expresses the sources of risk to health and ecosystems. An initial list for Hawaii was compiled from empirical information, such as counts of environmental stories in local newspapers, environment-related bills introduced in the legislature, and the findings of environmental impact statements for Hawaii projects (see Appendix A for details). This list was circulated to over 1,100 persons and organizations statewide with a request for comments and additions. More than 300 replies were received. As a result, a modified list of problem areas as shown in Table 1, Executive Summary, was used to organize the study.

The second step in environmental risk assessment is to invent or determine plausible scenarios of exposure to the stressors in each problem area. For example, industrial effluents may contain toxic chemicals. These effluents might contaminate public drinking water supplies and thus pose a risk to human health. An example of an ecosystem risk scenario would be construction activities that might erode soil, which is then carried by storm water into the coastal zone where the sediment would smother corals. Building reasonable scenarios requires knowledge of ecosystems, their structure, the movement of materials and energy through them, the properties of toxic chemicals and other stressors, and the behavior and sensitivity of impacted animals and plants. Exposure scenarios used assumptions tailored to Hawaiian climate and lifestyle such as daily diet and liquid intake (see Appendix D5).

This study generally does not use the so-called "worst-case scenario" because there is, literally, no worst case, and highly fanciful scenarios jeopardize the credibility of the entire assessment. If no plausible scenario of exposure can be postulated, there is no risk for the purposes of this study.

The third step is the characterization of the risk with quantification where possible. Risk is a product of the frequency of an adverse event and the magnitude of damage. How likely is it that exposure to a toxic chemical will occur, and what is the likely dose to an individual? How potent is the substance, and what is the result of poisoning to the body? How likely is the impact of some stressor on a valuable ecosystem site, how much of the resource is damaged, and how long will recovery take?

Finally, considerations of risk management come into the assessment because we are dealing with residual risk. What is now being done to reduce the risk and at what cost? Risk management options help determine the scope of risk assessment and enter into the setting of priorities for further attention. A risk that is now being properly managed with adequate funding may be ranked comparatively lower,but that does not suggest a cutback in the continuing level of attention. For example, risks to public health from Hawaii's sewage treatment and disposal systems are ranked lower in this study but continued proper maintenance and operation are, of course, essential. Furthermore, the sewage collection system is ageing and breaking down so that this facet of municipal sewage management appears to require more funding.

Cancer

This HERR study follows USEPA methods for estimating the additional risk of an individual contracting cancer from exposure to some carcinogen in the environment. Several hundred chemical compounds have been tested in animals. The procedure is to expose a group of test animals to several high levels (by inhalation, ingestion, or skin adsorption) of the suspected carcinogen for a period of time (usually the animals' normal lifetime). Postmortem inspection of each test animal is made for tumors or malignant neoplasms. The percentage (probability) of animals developing cancer at each dosage level is recorded. The slope of this line is then extrapolated to the low doses expected to be encountered by human beings who may be exposed to the chemical. Various assumptions are made as to the shape of the extrapolated dose-response curve as it approaches zero dose and zero response (e.g., whether a threshold exists or not). The slope becomes a unit cancer risk factor expressed in terms of $(mg/kg/day)^{-1}$.

When this factor is multiplied by a dose to an individual, expressed as mg/kg/day, the units cancel and the resulting number is the risk to the individual (probability) of contracting cancer during a lifetime of exposure at that dose level to the toxic agent in question. This is an excess risk over the sum of all other risks of contracting cancer (i.e., 0.3333 as noted above). Most of cancer risk is caused by lifestyle choices, including smoking, drinking, diet, and sunbathing. If, for example, lifetime exposure of a person to a carcinogenic material in the environment is calculated to yield an added risk of 1×10^{-4}, then the new total cancer risk for that person is 0.3334. This is a small additional risk but it is important to determine. Individuals are exposed to many natural and man-made carcinogenic substances, some of which are highly potent. It is assumed that risks are additive unless there is strong evidence for synergism or antagonism. Some exposures are involuntary (e.g., polluted air) and not avoidable by individual choice. Such risks, no matter how small, are generally not acceptable, because they are perceived to be unaccompanied by any benefit, and people feel helpless.

The expressed risk of contracting cancer is not the same as the risk of death. All cancers are not ultimately fatal. According to the DOH, 53% of cancer patients survive at least 5 years. One out of four deaths in Hawaii is caused by cancer, so that risk of death by cancer is 0.25. Toxic substances cause tumors at various sites in the body and different cancers have different lethalities.

Another useful way of expressing risk is the annual cancer incidence due to exposure to some specific carcinogen. This is the number of new cases of cancer in a population each year. This carcinogen-specific incidence depends on the number of people exposed to varying concentrations of that carcinogen. The USEPA has made estimates for the national population for a number of cancer-causing agents. Since Hawaii's resident population (1.1 million in 1990) is about 1/250 of the U.S. total, factoring the national data on incidence to this state would predict an annual cancer incidence of 4520 cases. However, Hawaii will experience a total of 3600 new cases of cancer in 1992 according to the American Cancer Society (Cancer Facts and Figures-1992). This is less than the national incidence rate. Likewise other national data may not apply to Hawaii. The expected death rate in Hawaii in 1992 from cancer is 138 per 100,000 population (1700 deaths); this rate is the third lowest in the United States. The national average is 171.

Non-Cancer Diseases

Risks of contracting diseases other than cancer from exposure to toxic agents in the environment are estimated in this study according to procedures of the USEPA. The potency factor is called a reference dose (RfD) or reference concentration (RfC) and is the maximum daily exposure that is unlikely to cause deleterious health effects. The RfD is also derived from animal test data as described earlier.

Because of the variety of effects associated with non-cancer diseases, morbidity categories are established for comparing health effects (personal communication, Dr. Gerald Hiatt, USEPA Region IX):

- Observable - these effects are detectable but may not show a disability (e.g., change in the level of an enzyme or low weight gain in infants).
- Serious - development or behavioral abnormalities and/or dysfunction of an organ.
- Catastrophic - death, shortened life, severe disability.

This HERR study does not usually use the most exposed individual for risk characterization; rather, assumptions are chosen for an average reasonable exposure scenario for the general population. In some instances, a specially identified sub-population may be exposed differently and its risk assessed separately. A maximum reasonable exposure may sometimes be included to test the sensitivity of a scenario.

Risk Ranking Guidelines

The following guidelines are used in this study to bring consistency to the ranking exercise. Where quantitative, probabilistic risk assessment is possible, the rankings are straightforward. Where qualitative information is important, group consensus among technical professional experts is attempted. The demarcations between higher, medium, and lower rankings are not "bright lines," and scientific uncertainties enter into the judgment of comparative risk. In general, where available data indicate that two risks are about the same calculated magnitude, the more certain assessment of the two would be ranked as the higher priority for attention.

Three levels for comparison of risks constitute priorities for governmental attention as suggested by this HERR study. Environmental health problem areas (sources of hazard) are assigned to comparatively higher, medium, or lower risk levels, but are not ranked within each level.

This guideline recognizes that EPA standards vary in absolute risk by as much as four orders of magnitude, and some include consideration of risk management when they are set. The laws mandating these standards specify that human health is to be protected with an adequate margin of safety. Therefore, whenever State of Hawaii or USEPA regulations, environmental quality standards, or exposure limits are being consistently complied with, the risk is placed in the LOWER category.

The factors considered in risk ranking are:

Cancer - excess lifetime risk of contracting cancer for an individual in the general public (or in a specially exposed population) from average exposure to estimated reasonably expected concentration of a carcinogen in the environment

- excess annual incidence of cancer in the general population
- epidemiological association of an environmental contaminant with excess incidence of cancer

Non-Cancer - ratio of the estimated reasonable average exposure dose to reference dose or reference concentration

- morbidity category for the toxic agent
- epidemiological association
- the proportion of the population exposed

For cancer - to warrant a HIGHER priority ranking in this HERR study, in the general Hawaii population, the risk to an individual should be greater than $1x10^{-5}$ (1 in 100,000), or the predicted excess annual incidence should be greater than 10 cases, or the epidemiological association should be strong.

A MEDIUM ranking would result if the annual incidence was increased by more than one case, or the individual excess risk in the general population was between $1x10^{-6}$ and $1x10^{-5}$, or the individual risk in a special population was $1x10^{-4}$ or greater.

A LOWER ranking would be given where State of Hawaii and/or USEPA health protection regulations are met, or the individual lifetime excess risk was less than $1x10^{-6}$.

For non-cancer - to warrant a HIGHER priority ranking, the ratio of dose to reference dose should be greater than one, and the morbidity category should be catastrophic, with the general population consistently exposed.

A MEDIUM ranking would result if the dose/RfD was greater than one, but the morbidity category was only serious, or only specially exposed populations were at risk, or the exposure was sporadic.

If the dose/RfD is less than one (i.e., regulations are met) or if the morbidity category is only OBSERVABLE, then the risk is ranked at the LOWER level.

FINDINGS--RISKS TO HUMAN HEALTH

Following the above process for all significant environmental problem areas produced the set of risks that were assessed by the HERR study. Some of the original concerns were found to be unimportant for Hawaii. Other risks could not be assessed because data were not available or uncertainties are as yet too great. Table 1-2 presents a comparison of hazards based on their risk to human health. The result is an indicated order of priority for further attention by the people of Hawaii. Social, economic, cultural, and political factors must be added, however, to complete Risk-Based Strategic Planning.

OUTDOOR AIR POLLUTION IN HAWAII

The lack of significant industrial development and the unique meteorology of the Hawaiian Islands tend to mitigate the buildup of outdoor air pollutants. Hence, the exposure of Hawaii's population to outdoor air pollutants is far less than that of mainland U.S. residents and of most urban residents worldwide. Prevailing northeasterly trade winds in the Hawaiian Islands of between 5 and 25 mph exist approximately 90% of the time in the summer months and 50% of the time in the winter months. In most cases, point-source industrial emissions are located downwind (during tradewinds) of urban areas (such as at the Campbell Industrial Park on Oahu), and pollutants from these sources are blown back onshore only during occasional Kona or southwest winds. Sources of outdoor air pollutants considered in this study include industry (power plants,

Table 1-2
Assessment of Risks to Public Health from Environmental Hazards

Environmental Problem Area and Hazard	Risk Assessment and Ranking
Outdoor Air Pollution **Criteria Air Pollutants** (particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, lead)	Lower risk to the general population: Hawaii consistently attains all National Ambient Air Quality Standards at all monitoring sites. Medium risk to small populations that spend appreciable time in automobile-congested outdoor areas with restricted ventilation: exposure to carbon monoxide may be health-damaging.
Toxic Air Pollutants (emissions of toxic chemicals such as benzene, arsenic, asbestos, radionuclides, and vinyl chloride)	Lower risk to the general population. Refinery emissions were assessed using benzene as the most potent carcinogen and naphthalene as the most toxic non-cancer disease agent. The individual cancer risk is far less than one in a million; cancer incidence in the most exposed population is less than one excess case/yr. The ratio of dose to reference dose for naphthalene is far below one. Lead from a coal-fired power plant was assessed and the blood lead level predicted did not exceed the EPA-recommended action level. H-Power emissions were assessed using dioxins and furans as the most potent carcinogens. The risk to individuals is far less than one in a million. Medium risk to commuters and members of the public involved in automobile refueling - from benzene-containing vapors. Exposure data for Hawaii are lacking, but the potency of benzene as a carcinogen suggests these special populations might be at risk. Relevance of intermittent exposures is uncertain. Not assessed was the risk from cane smoke. Efforts are currently under way that may provide data for these calculations.
Toxic and Hazardous Materials and Waste (potential Superfund sites, storage, treatment, and disposal)	Lower risk to the general population from storage, transport, accidents, or spills. Spill reports do not show exposures. Military wastes are isolated from contact by the public. No hazardous wastes are permanently stored in Hawaii. The Aiea Laundry site risk assessment was reviewed, and cancer risk to children is one in a million. Medium risk to specially exposed populations from certain contaminated sites. For example, the individuals in the community downwind from the Kailua-Kona landfill, which often catches fire, would incur a risk from benzene of cancer to one in 100,000 if this situation continues for a 20-year period of intermittent exposures. Not assessed was the risk from leaking underground storage tanks because of lack of data; however, the ubiquity of the tanks and the high cancer potency of benzene, which is a constituent of some petroleum products, warrant more monitoring. Exposure to lead from a variety of sources, and ingestion of water and dust, is judged to be a higher risk to children, although the lack of monitoring data and blood lead levels preclude quantitative risk assessment at this time. Increased monitoring is under way. Dumpsites with lead-contaminated oil in Waianae-Oahu may pose a significant risk to children playing around drums when leaks occur. Medium risk from lead to special population on the Big Island using roof catchments. Lower risk from arsenic residues in and around Hilo Bay.

Table 1-2 (continued)

Environmental Problem Area and Hazard	Risk Assessment and Ranking
Industrial Wastewater Discharges (toxic chemicals, heat, nutrients, pathogens)	Lower risk to health of general population. No significant violations of permits: indication of exposure via drinking water contamination or water contact recreation.
Drinking Water (toxic chemicals and pathogenic organisms)	Lower risk to the general population. All tap water at public water systems meets state and federal standards. Untreated raw water supplied to drinking water systems does not pose risks greater than one in a million except from a few wells. Continuous monitoring is necessary to assure treatment when required. Some drinking water sources contain bacteria and are chlorinated, but the resulting trihalomethanes are below the maximum concentration limit.
Municipal Wastewater Treatment and Disposal (deep ocean outfalls, sewage spills and leaks, recreational water quality, proposed secondary treatment)	Lower risk to the general population. No evidence of significant transport of treated sewage from deep ocean outfalls to coastal recreation areas. Sewage spills and leaks require beach closing; health is protected but economic damage occurs. Hawaiian municipal wastewaters do not contain significant quantities of toxic chemicals or heavy metals.
Nonpoint Sources of Water Pollution (sediment, nutrients, toxic chemicals, and pathogens)	Lower risk to general public. Medium risk to special populations who eat large amounts of fish from Manoa Stream or Ala Wai Canal (and perhaps other waters) that are contaminated with pesticides. Runoff waters can pick up toxic chemicals and pathogens that may be delivered to poorly mixed receiving waters (e.g., Kapahulu groin area, Ala Wai Canal, Waimanalo Bay).
Indoor Air Pollution (environmental tobacco smoke, combustion products, chemicals in consumer products)	Higher risk to general population based on extrapolation of mainland data. Uncertain because no Hawaii-specific data are available. Need to: monitor actual indoor air concentration, survey sales and use of toxic materials, and measure ventilation rates.
Accidental Releases of Toxic Materials (leaking underground storage tanks, H_2S from geothermal development, industrial or military activities)	Lower risk to general population. No plausible scenario of exposure other than to small groups for short times in rare cases of accidents.

refineries), mobile sources (automobiles, buses), area sources (dry cleaners, gasoline stations), and other special activities (e.g., agricultural burning).

Data sources included:

1. Air quality criteria pollutant data from DOH Clean Air Branch monitoring stations;
2. Operating permits and Notices of Violation (NOVs) in the files of the DOH Clean Air Branch;
3. Estimated toxic air emissions as listed in the Toxic Release Inventory, SARA Title III, from the DOH Hazard Evaluation and Emergency Response Branch;
4. Special studies conducted by the UH School of Public Health, the American Lung Association of Hawaii, UH Department of Urban and Regional Planning, and DOH; and
5. Special studies on air toxic emissions that were conducted on the U.S. mainland, which have potential transferability to Hawaii.

Regulatory policy and environmental standards for managing outdoor air pollution can be divided into those directed toward monitoring and control of "criteria" air pollutants and those directed toward the monitoring and control of "air toxics" (both particulate and gaseous pollutants).

Hazards and risks addressed in the HERR study are listed in Table 1-3.

Criteria Air Pollutants

Through the 1970 (and later) amendments to the Clean Air Act, the EPA established National Ambient Air Quality Standards (NAAQS) for certain "criteria" pollutants to protect human health and welfare. The act requires that the states be responsible for implementation, maintenance, and enforcement of these standards. DOH maintains 14 ambient air quality monitoring stations to establish compliance with these standards. Table 1-4 lists the state and federal ambient air quality standards. Table 1-5 shows the location of 13 air monitoring

Table 1-3

Hazard/Risk and Basis for Assessment

Hazard/Risk	Basis for Assessment
1. Criteria Air Pollutants (suspended particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, ozone, and lead)	Air Monitoring Data 1985-89 Modeling of emissions from power plants Special studies of CO hot spots
2. Air Toxics	Identification of primary emissions from SARA Title III data (refineries selected as major source category) Modeling of emissions from refineries Modeling of emissions from H-Power municipal incinerator Modeling of emissions from power plants Review of special studies from gasoline marketing
3. Volcanic Emissions (Vog)	Review of DOH studies on vog Review of American Lung Association studies on vog
4. Agricultural Burning	Review of DOH studies on sugar cane burning Review of status of current UH project on sugar cane burning

sites (a fourteenth site on Lanai was added more recently) and the number of times state and federal standards have been exceeded during the years 1985-87. More recent data from DOH would be helpful to this study but they were not yet processed in a form that could be made available. The State of Hawaii is considered to be in "attainment" of the federal NAAQS for the protection of human health from exposure to criteria air pollutants. A review of DOH air pollution permits and notices of violations did not reveal any violations that would pose significant health risks to the public. For these reasons, the working group recommended that exposure to criteria air pollutants be placed in the category of problem areas that pose lower risk to human health.

Table 1-4
National and Hawaii Ambient Air Quality Standards

POLLUTANT	AVERAGING PERIOD	ALLOWABLE CONCENTRATION (microgram/M^3) National Standards Primary	Secondary	Hawaiian Standards
Particulate Matter (PM)	24-Hour	260	None	150
	Annual	75	None	60
Particulate Matter Less Than 10 Microns (PM-10)	24-Hour	150	150	None
	Annual	50	50	None
Sulfur Dioxide (SO_2)	3-Hour	None	1,300	1,300
	24-Hour	365	None	365
	Annual	80	1,300	80
Nitrogen Dioxide (NO_2)	Annual	100	100	70
Carbon Monoxide (CO)	1-Hour	40,000	None	10,000
	8-Hour	10,000	None	5,000
Ozone (O_3)	1-Hour	235	235	100
Lead (Pb)	Calendar Quarter	1.5	1.5	1.5

Table 1-5
Number of Times Federal Primary and State Air Quality Standards Exceeded
(January 1985 to December 1987)

	Barbers Point, Oahu	Pearl City, Oahu	Sand Island, Oahu	Dept. of Health, Oahu	Liliha, Oahu	Waikiki City, Oahu	Waima-nalo, Oahu	Lihue, Kauai	Kahu-lui, Maui	Kihei, Maui	Lahaina, Maui	Hilo, Hawaii	Kona, Hawaii
<u>CARBON MONOXIDE</u> (1-Hour Standard)													
1. No. of samples	NS	NS	NS	1035	NS	998	NS	NS	NS	NS	NS	NS	NS
2. No. of times Federal standard exceeded	NS	NS	NS	0	NS	0	NS	NS	NS	NS	NS	NS	NS
3. No. of times State standard exceeded	NS	NS	NS	5	NS	6	NS	NS	NS	NS	NS	NS	NS
<u>PARTICULATE MATTER</u> (24-Hour Standard)													
1. No. of samples	44	158	NS	169	176	NS	170	46	36	45	NS	35	74
2. No. of times Federal standard exceeded	0	0	NS	0	0	NS	0	0	0	0	NS	0	0
3. No. of times State standard exceeded	3	0	NS	0	3	NS	0	0	1	5	NS	0	0
<u>SULFUR OXIDES</u> (24-Hour Standard)													
1. No. of samples	160	NS	NS	164	NS	NS	NS	NS	32	35	NS	43	71
2. No. of times Federal standard exceeded	0	NS	NS	0	NS	NS	NS	NS	0	0	NS	0	0
3. No. of times State standard exceeded	0	NS	NS	0	NS	NS	NS	NS	0	0	NS	0	0
<u>OZONE</u> (1-Hour Standard)													
1. No. of samples	NS	NS	1029	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2. No. of times Federal standard exceeded	NS	NS	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
3. No. of times State standard exceeded	NS	NS	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>PM-10</u> (24-Hour Standard)													
1. No. of samples	107	151	NS	NS	103	NS	NS	117	NS	38	8	NS	NS
2. No. of times Federal standard exceeded	NS	NS	NS	NS	0	NS	NS	0	NS	0	0	NS	NS
<u>LEAD</u> (24-Hour Standard)													
1. No. of samples	NS	NS	NS	119	178	NS	NS	NS	NS	NS	NS	NS	NS
2. No. of times Federal standard exceeded	NS	NS	NS	0	0	NS	NS	NS	NS	NS	NS	NS	NS
3. No. of times State standard exceeded	NS	NS	NS	0	0	NS	NS	NS	NS	NS	NS	NS	NS

NS = That pollutant is not sampled at that site.

However, a number of special studies have been conducted (Flaschbart and Brown 1985) suggesting that personal exposures to carbon monoxide in certain outdoor microenvironments in Hawaii (parking garages and commercial districts) may pose potential health risks of concern. A carbon monoxide (CO) survey of business outlets adjacent to the lower level Ala Moana Parking area showed that the national CO one-hour standard (35 ppm) was exceeded 60% of the time. The 8-hour federal standard (9 ppm) was exceeded 84% of the time. Although the population exposed in these microenvironments is small, the frequency of occurrence and the health effects, which include impairment in visual function, time discrimination, and psychomotor performance, are of sufficient severity to warrant ranking CO exposure in special microenvironments as a medium health risk. Additional data are needed on how many similar parking structures exist, how many people are exposed, and the range of times and concentrations of exposures.

Toxic Air Pollutants

Section 112 of the 1970 Clean Air Act amendments authorized the EPA to establish special National Emission Standards for Hazardous Air Pollutants (NESHAPs), but to date, standards have been promulgated for only eight substances: arsenic, asbestos, benzene, beryllium, coke oven emissions, mercury, radionuclides, and vinyl chloride. Duirng the 1980's many states developed their own Air Toxics Programs, and some even promulgated state standards for certain pollutants. By January 1990, 36 states had developed air toxics emission inventories (USEPA 1990) to assist their regulatory agencies in characterizing the problem. The State of Hawaii has not yet developed an air toxics inventory, and the last criteria pollutant inventory dates back to 1981. However, in response to the Clean Air Act amendments of 1990, which list 189 substances (Appendix G) presumed to require regulation as air toxics, it is likely that the State of Hawaii will be required to begin the collection of more detailed information regarding the emissions and presence of air toxics in the outdoor environment.

The working group on outdoor air quality based its analysis of the potential for exposure to air toxics in Hawaii on information reported to DOH under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA), also known as Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986. Under this act, certain businesses are required to submit yearly reports on the quantity of toxic chemical emissions that their facilities release to the air, water, and land environment. The final ruling describing these requirements for the Toxic Chemical Release Inventory (TRI) was published in the Federal Register on February 16, 1988. A facility is required to report under this act if it meets the following three criteria:

1. Conducts manufacturing operations (included in Standard Industrial Classification codes 20-39);
2. Has 10 or more full-time employees; and
3. Manufactures, imports, processes, or otherwise uses any of the currently 318 toxic chemicals listed under the rule in amounts greater than the "threshold" quantities specified.

The working group performed a toxic concentration screen on the chemicals listed in the Hawaii TRI for which toxicity data were readily available, based on the volume of annual release of each chemical and the potency factor or reference dose of that chemical. For Hawaii, benzene was identified as the most important carcinogen on the list and naphthalene as the most important non-carcinogen.

Because the major sources for both benzene and naphthalene in Hawaii are the two refineries on Oahu at Barbers Point, an EPA screening-level ambient air model (SCREEN) was used to estimate worst-case 1-hour concentrations for each compound. Emissions were considered to be constant over the year, and hourly emissions were estimated based on the annual TRI data. Previous dispersion modelling exercises concerning industrial emissions from Campbell Industrial Park predicted that during periods when tradewinds do not blow emissions offshore, the maximum downwind concentrations of pollutants at ground level occur at Makakilo. This is where maximum population exposure is expected. Five years of meteorological data collected at Barbers Point from January 1967 to December 1971 indicate that winds blow from the southwest very infrequently. Including winds from the south-southwest and from the west-southwest, the number of days that Makakilo is exposed to the highest 1-hour concentration is only 7 days per year. From this information the individual lifetime cancer risk for benzene exposure from both refineries was calculated to be 8 x 10^{-8}. The population potentially exposed in census tract 86.01 is 10,246 according to the Department of Business and Economic Development's State of Hawaii Data Book 1990. This yields an excess incidence of cancer cases of less than 0.008 per year. For non-cancer risks, a similar calculation for naphthalene yields a ratio of actual dose to the standard reference dose of 1:1000. Thus, the ranking of both cancer and non-cancer risks from exposure to air toxics from the refineries is comparatively <u>lower</u> (see Appendix G for details).

Recently an Authority to Construct (ATC) permit application was filed for a proposed 180-MW coal-fired steam electric cogeneration plant. An air quality analysis of potential impacts revealed that all concentrations of criteria pollutants would be below applicable federal and state standards. The projected ambient concentration of lead was run through the EPA LEAD4 model to predict a blood-level concentration of lead in the exposed population. This model indicated that blood lead would not be expected to exceed the action level recommended by the EPA. Therefore, risks associated with the coal-fired power plant were ranked <u>lower</u>.

Sources of air toxics not included in the TRI but nevertheless of potential concern include mobile sources, area sources, municipal incineration, and agricultural burning. The air toxic of most concern from mobile sources is benzene, which is a constituent of gasoline (1-5%). Exposure to benzene during automobile commuting and refueling may be of concern. Exposure during commuting refers to the exposure to unburned fuel (benzene) in exhaust fumes received by occupants of cars in congested slow moving traffic.

There are no Hawaii-specific data available to assess the potential exposures from these sources. For example, average windspeed may be higher here than on the mainland; thus, dispersion of vapors may be more rapid. The median concentration of benzene measured in ambient air in typical mainland urban environments is 1.8 ppbv (parts per billion by volume) (USEPA 1988).

A calculation of potential risks associated with exposures to gasoline vapors is shown in Appendix G. Substantial uncertainties as to health effects occur in adding up repeated short exposure times to calculate a lifetime dose. The application of the standard benzene cancer potency factor under these conditions is also controversial. Subject to these uncertainties, lifetime risks to an individual both from commuter exposure to traffic fumes and from refueling operations are estimated to be 10^{-5} to 10^{-6}. These risks are present for a significant fraction of the Hawaii population, since over 90 percent live in urban areas. There is also a potential for exposure of those individuals residing or working near leaking underground storage tanks that contain fuels comprising benzene. Due to lack of specific data, this risk cannot be quantified at this time. The general population risk due to exposure to benzene in gasoline vapors is, however, ranked <u>medium</u>.

The potential for public health risk from toxic emissions from the H-Power municipal incinerator was reviewed. A recent review of municipal incineration indicates that a possible risk to human health is air inhalation and ingestion of produce, fish, beef, dairy products, and breast milk contaminated with 2,3,7,8 tetrachlorinated dibenzodioxins and dibenzofurans (TCDD and TCDF) (Lewin et al. 1991). Data on TCDD and TCDF emissions from the H-Power incinerator were made available from the Hawaii DOH. Air modeling of these emissions was conducted to predict downwind concentrations in populated areas. As with the refinery model, meteorological data indicate that a wind direction that would blow these emissions into populated areas occurs infrequently. Using a toxic equivalency method to assess the total risk associated with all isomers of TCDF and TCDD, the annual lifetime excess cancer risk for maximally exposed individuals is on the order of 10^{-9}. Health risks associated with exposure to toxic pollutants from H-Power are therefore ranked <u>lower</u>.

It should be noted that older incinerators are known to have TCDD, TCDF, and metal emissions sometimes several orders of magnitude higher than those from the newer incinerators. No data were available on emissions associated with the Waipahu incinerator. Because this incinerator is older, has shorter stack heights, and is located in a more populated area, it is recommended that future emission data be collected from this incinerator (if it continues operation) and that health risks to the nearby population be assessed.

Although this study specifically excluded risks from natural disasters and naturally occurring air emissions, the working group decided to review existing knowledge regarding health risks from volcanic emissions (vog) for comparative purposes. Epidemiological surveys carried out by DOH have shown that on the island of Hawaii, there are twice the frequency of medical insurance claims for respiratory complaints in vog areas as compared with non-vog areas. Sulfate levels measured in West Hawaii are comparable to levels found in mainland US areas with sulfate haze problems (Morrow 1991). A background study of air quality at the Kilauea East Rift during periods of volcanic emissions showed air quality to be far superior to that measured in both urban and rural areas on the mainland U.S. (Table 1-6). This area of the Big Island is upwind of the volcano most of the time. Downwind sulfate levels have been found 3-8 times higher than average conditions (Morrow 1991). There has never been a violation of the state or federal standards for sulfur dioxide reported in Hawaii although intermittent monitoring may have missed occasional peak periods. Hydrogen sulfide concentrations occur widely on the volcano and at geothermal power sites at perceptible levels; however, these odor nuisance levels are below health effect threshold levels. The DOH has established an ambient concentration limit for H_2S of 25 micrograms/m^3, about 5 times the odor perception threshold.

Without further correlation of reported respiratory complaints with actual measured volcanic emissions of pollutants, the risk to the health of the general population from vog is ranked in the lower category. Children permanently residing in West Hawaii downwind from the volcano may be at a greater risk and should be studied more closely.

Health risks due to smoke generated from burning sugar cane were also addressed by the working group. Combustion of sugar cane in the field produces airborne particulates, volatilized pesticides,

Table 1-6

Air Quality Data from Big Island* Compared with U. S. Mainland

	Measured Concentrations	Annual Standard
	(microgram/m^3)	
TSP (Total Suspended Particulates)		
Big Island	8-30	
Mainland-urban	80	75
Mainland-rural	50	
Respirable Particulate		
Big Island	2	
Mainland-urban	24	50
Mainland-rural	15	
Sulfates		
Big Island	1-3	
Mainland (East of Mississippi)	35	
	(ppbv)	
Sulfur Dioxide		
Big Island	0.3-4.2	
Mainland-urban	11	30
Remote global	0.2	
Hydrogen Sulfide		
Big Island	N.D.-25	
Human Perception level	10-100	
Health Effects threshold	10,000-20,000	

*Baseline Air Quality Kilauea East Rift, Report to Hawaii DBED by J. Houck, Omni Environmental, 1985.

amorphous biogenic silicate fibers, and other products of incomplete combustion. A 1986 study was conducted in Hawaii by the EPA to analyze samples of sugar cane smoke. Ninety percent of the particles measured in the smoke were in the respirable-size range. Levels of pesticides reported in that study are somewhat controversial due to the inability of other laboratories to duplicate the data. Current epidemiological studies reveal a possible association of mesothelioma and exposure to cane smoke. A review by the National Institute for Occupational Safety and Health of a 1987 study by Kirkham shows no association of asthma with census tracts near sugar cane-growing areas in Hawaii. Currently the data on biogenic silica as a causative agent of lung cancer or mesothelioma are limited and circumstantial. The DOH and the UH School of Public Health are conducting an epidemiological investigation on acute asthma and sugar cane smoke on Maui and Kauai. The HERR study determined that due to large uncertainties in the exposure of the public to toxic agents in sugar cane smoke and the uncertainties in epidemiological associations with adverse health effects, this risk cannot be estimated until current studies have been completed.

INDOOR AIR POLLUTION

Many people associate health-damaging air pollution with releases of pollutants into outdoor air. In recent years, however, there has been growing evidence that some of the largest exposures to important pollutants actually occur indoors in residences. This is due to two factors:

- People spend most of their time indoors and thus, on average, breathe much more indoor than outdoor air.
- Although indoor sources produce relatively small amounts of pollution compared to many outdoor sources, concentrations of concern to health can still occur because the pollution is mixed in a relatively small volume of air.

There are six basic categories of indoor pollution found to be most important in the United States:

- Tobacco - Environmental tobacco smoke (ETS)
- Combustion - Nitrogen Oxide (NO_x) from gas cookstoves and kerosene heaters; particles and organic chemicals from wood-heating stoves
- Materials - e.g., formaldehyde from new carpets; asbestos in insulation
- Consumer products - Pesticides; methylene chloride in paint remover; paradichlorobenzene from air fresheners; trichloroethylene from dry-cleaned clothes, etc.
- Ground under the building - Radon and its radioactive daughter products
- Biological processes - Mold; mildew; fungal spores

The degree to which these sources are problems in a household depends not only on their strength but also on how well the residence is ventilated. In general, indoor concentrations decrease with increasing ventilation rates, depending, of course, on how much pollution is in the replacement air from outside.

A significant amount of research has been undertaken on the U. S. mainland in recent years, particularly with regard to the preceding first five categories (contributions from biological processes are less well studied). Unfortunately, however, little work seems to have been done in Hawaii itself. Thus, for the moment it is necessary to extrapolate from mainland data.

In general, Hawaii's conditions would seem to lead to lower exposures than typical on the mainland, although there are influences in both directions.

- Time spent indoors: Given the year-round mild climate and associated lifestyles, the average time spent indoors is presumably less in Hawaii. We have assumed that people spend

20% less time in their residences than is typical on the mainland.

- Mixing volume per person: Because of high land prices, the average household in Hawaii is assumed to have 10% less floor area than households on the mainland. All else (source and ventilation) being equal, this would tend to raise indoor pollutant concentrations in Hawaii residences by 10% over the mainland.
- Ventilation: Hawaii housing, although smaller in floor area, is undoubtedly substantially better ventilated on average than typical on the mainland. Unfortunately we were not able to find any ventilation measurements done in Hawaii residences, but there is a 17-state mainland review that shows the average ventilation rate to be about 2.3 air changes per hour (ACH), with a median at about 0.65 ACH (Pandian et al. 1992). To indicate the range of uncertainty, we assumed that Hawaii residences are 2-8 times better ventilated. See Appendix G-4 for a discussion.
- Outdoor pollution: Hawaii is blessed with quite low ambient pollution levels.

Sources:

Tobacco: The smoking rate in Hawaii is 27% of the population, about 15% less than the mainland (31%).

Combustion: Gas cooking stoves are used by about 15% of Hawaii's residences, as compared to 40% on the mainland. Heating stoves are rare, however, except in a few upland areas. Incense and mosquito coils are probably burned more frequently than on the mainland.

Materials: Asbestos for heat insulation is less important in Hawaii, although, as on the mainland, it was once commonly installed for fire safety and sound insulation. It is difficult to think of a reason that Hawaii households would have significantly different amounts of new furniture and carpets, which are the main contributors to formaldehyde levels. Some of the highest mainland exposures, however, are found in mobile homes, which are rare in Hawaii.

Consumer products: Here would seem to be an area where Hawaii's situation may lead to higher indoor emissions. In particular, given our nearly tropical conditions it would not be surprising if household pesticide use is greater than on the mainland. Dry cleaning is presumably less common. High-rise apartments and small lots may mean less use of gardening chemicals. More data are needed to avoid conjecture.

Ground: There have been radon surveys in Hawaii that indicated substantially lower levels than on the mainland. The households monitored showed a mean radon level only 6% of that found on the mainland (0.1 instead of 1.6 picocurie/liter--Phillips 1990). It is not clear, however, how much of the difference is due to better ventilation and how much is due to lower ground concentrations of radon-generating minerals.

Biological processes. Here, also, because of our warm and humid conditions, it is possible that source strengths may be higher than the mainland average, although presumably lower than in the even hotter and more humid southern mainland states.

With these differences in mind, the mainland Environmental Risk Ranking (ERR) studies can be examined. Because of the relative ease of estimation compared to other effects, most emphasis has been on cancer cases and deaths.

Louisiana Environmental Action Plan (LEAP). Although not quantifying the results, LEAP rated indoor air pollutants to have a "Very High Risk Ranking." Highest among the cancer risks were those from ETS and volatile organic compounds (originating mainly from materials and consumer products). High risk was also assigned to non-cancer effects. The overall "very high" categorization was made because of the "universal and continual" nature of the risks.

Vermont (VERR). The Vermont study found indoor air pollution to be at the high end of their range for human health. In summary, they found annual impacts (excess deaths per year) to be as follows [in brackets are risks per million persons, based on a population of 590,000 and a lifetime of 70 years]:

- ETS: 6-12 cancer deaths per year [700-1,400] and thousands of non-cancer illnesses (e.g., respiratory infections in children)
- Formaldehyde: 1-14 cancer deaths per year [120-1,700]
- Asbestos: near zero
- Radon: 9-68 lung cancer deaths per year [1,000-8,000]
- Vermont total: 10-130 cancer deaths per year [1,200-15,000]

Washington (WERR). In spite of quantitative estimates of risk similar to those of VERR, the Washington State study rated chemical indoor air pollution to be a medium risk and radon to represent a low-medium risk. It found annual excess cancer cases (not deaths as in VERR) as follows [in brackets are risks per million, based on a population of 4.75 million and a lifetime of 70 years]:

- ETS: 147 cancer cases per year [2,000]
- Formaldehyde: 69 cancer cases per year [1,000]
- Asbestos: 4 cancer cases per year [30]
- Consumer products: 110 cancer cases per year [1,500]
- Woodsmoke: 16 cancer cases per year [200]
- Radon: 300 cancer cases per year [4,000]
- Total: 650 cancer cases per year [9,000]

Hawaii. Because of their completeness, the WERR risks have been used as the basis for estimating risks of excess cancer deaths due to these hazards in Hawaii. Unless stated otherwise, all the mainland risks have been lowered by a factor of 1.1 (1.2/1.1) to account for fewer person-hours and less floor area in Hawaii residences. The resulting risks were then lowered by additional factors of 2-8 to give a range that accounts for the greater ventilation in Hawaii residences. In brackets are the ranges for the lifetime population risks.

- ETS: 3-13 cancer cases per year [210-850], considering the lower smoking rate in Hawaii. A recent review of risk estimates by USEPA has further strengthened the case against ETS.
- Asbestos: Near zero cancer cases per year.
- Formaldehyde: 2-7 cancer cases per year [110-450].
- Consumer products: 6-24 cancer cases per year [380-1,500]. Risk is lowered here to a lesser extent (2x) than for other sources because of possible greater usage of household chemicals in Hawaii. This assumes, therefore, that the advantage of increased ventilation is partly balanced by greater indoor emissions.
- Woodsmoke: Near zero, although potentially a significant risk to small upland populations.
- Radon: 4 cancer cases per year [250]. This is based on the published estimates of lifetime risk of 4,000/million at 1.6 pCi/l extrapolated to the measured Hawaii level of 0.1 pCi/l.
- Biological products: Uncertain

<u>HAWAII</u> <u>TOTAL:</u> Assuming additivity of these excess risks, Hawaii has 15-48 cancer cases per year from indoor air pollution; an average individual lifetime risk of about 1,000-3,000 per million (1-3 per thousand). Since most of the cases would be lung cancer, for which the case fatality rate is about 90%, some 13-43 excess cancer deaths per year might be expected from indoor air pollution in Hawaii.

<u>Conclusion</u>

Although the lack of actual local data makes these estimates uncertain, the widespread and daily nature of the exposures and the resultant potential for significant ongoing health damage in the general population warrant placing indoor air pollution in the HERR <u>Higher</u> risk category.

Needed to pin down the actual indoor air pollution risks in Hawaii is information on:

- Surveys of sales and household usage of consumer products containing toxic chemicals (e.g., pesticides, paint strippers). These seem to be potentially the chief sources of indoor risk.
- Measurement surveys of ventilation rates in Hawaii residences.
- Actual air concentrations of, and human exposures to, critical pollutants in representative dwelling places.

Although not part of the HERR study, it might also be well worthwhile to examine indoor nonhousehold locations where people spend significant amounts of time, such as in schools and office buildings.

HAZARDOUS WASTE

Data relevant for assessing the potential for human exposure to toxic and hazardous materials in Hawaii were collected with the assistance of DOH; the office of the U. S. Commander in Chief, Pacific (USCINCPAC), of the U. S. Department of Defense; and the U. S. Coast Guard Marine Safety Office. Data provided by DOH included the Toxic Release Inventory (as discussed earlier), the list and status of current CERCLA sites in Hawaii, the 1990 Oil and Hazardous Substance Spill Report assembled by the Office of Hazard Evaluation and Emergency Response (1990e), the Leaking Underground Storage Tank Spill Log, RCRA (Resource Conservation and Recovery Act) permits and listing of any notices of violation (NOVs), and special studies relating to potential events of toxic and hazardous material contamination.

Current and Future Management of Hazardous Waste

A review of potential environmental problems related to management of currently generated hazardous chemical wastes and projected quantities for the next two decades begins with Hawaii's Hazardous Waste Management Capacity Assurance Plan (CAP) of October

1989 and the DOH report, Hazardous Waste Management in the State of Hawaii, Feb. 1990.

Data on contaminated sites in the municipal, industrial, and military sectors demonstrate past mismanagement of hazardous wastes prior to the 1980s. The ongoing DOH program of managing these wastes appears to be effective in reducing risks to public health and will, of course, continue.

The Hawaii CAP notes that about 1,500 tons of hazardous wastes were generated in Hawaii in 1987. Inasmuch as Hawaii is a non-industrial state, it is not surprising to find that this is a relatively small quantity (0.1% of the total generated by the 14 Western states). In contrast, California, with 25 times Hawaii's population, generates 600 times as much hazardous waste--about 900,000 tons annually. It is forecast that Hawaii's hazardous waste generation in 2009 will be about 2,800 tons.

In 1987, military activities were generating about one-half of Hawaii's hazardous wastes. That percentage is now decreasing.

A significant share of Hawaii's hazardous wastes are now treated (partly made into reuseable materials) locally, with the remainder being shipped to other western states for proper disposal. There is now one permitted temporary treatment, storage, and disposal facility in Hawaii. It is unlikely that Hawaii will have any economic justification for building new facilities for ultimate disposal of such wastes in the foreseeable future. An agreement between 14 Western states, described in the CAP, gives assurance that there will be proper and adequate disposal facilities available on the U. S. mainland for the ultimate disposal of the region's hazardous wastes for many decades to come.

Over the past decade, stringent EPA regulations for treatment, transport, storage, and disposal have motivated hazardous waste management. Controls have included a "cradle-to-grave" manifest system for accountability of the wastes. It is not surprising, then, that this study found no evidence of serious environmental problems in hazardous waste management. These risks to public health are, therefore, ranked lower.

Large Quantity Generators (LQGs) of hazardous wastes (greater than 1,000 kilograms per month) are regulated stringently, while Small Quantity Generators (SQGs 100 to 999 kilograms per month) are subject to only partial regulation. In Hawaii currently there are 40 LQGs, 350 SQGs, and 600 conditionally exempt generators.

The DOH is proceeding with prudent plans to encourage waste minimization, recovering or re-using waste materials, recycling on-site, recycling off-site, and pre-treatment of wastes to minimize costs of shipment to mainland disposal sites.

Hazardous Waste At Municipal and Industrial Sites

DOH is currently conducting hazard evaluation of a number of sites where hazardous wastes from past mismanagement are thought to occur. A hazard ranking system (HRS) is used to score each site; high-scoring sites become eligible for the National Priorities List (NPL), additional investigation, and federal funding for cleanup. The score is based on the amount of hazardous material, its toxicity, likelihood of contacting human beings, and other criteria. It is possible that a site would score high in the HRS solely on the basis of potential or actual damage to ecosystems and pose no threat to public health. The scores are confidential until a decision is made whether to include the site on the NPL. This HERR study is frustrated in assessing the risks to public health from candidate sites because of the current confidentiality of the data collected by the state DOH.

Contaminated municipal/industrial sites. As of July 1991, there were 133 potentially contaminated sites in Hawaii nominated for listing under the federal Superfund site program (CERCLA). A priority list of hazardous substances under this program is found in Appendix F4. The Hawaii sites on the CERCLA list are all in various stages of assessment, including discovery phase (DS), preliminary assessment (PA), and site investigation (SI). The hazardous materials working group reviewed this list. With the advice of the visiting EPA scientist (Mike Nalipinski) assigned to review the status of CERCLA sites in Hawaii, the working group selected four contaminated sites (1 military and 3 municipal/industrial) for further assessment of potential public health risks.

Military Hazardous Waste Sites in Hawaii (Installations Restoration Program, IRP)

Data on these sites are presented in Appendix F1.

Currently environmental problems are suspected at 228 sites at military installations, as a result of contamination in past years. As of December 1991, except for one site (Aiea Laundry), no data were available on contaminant concentrations, exposure potential, and doses, which are necessary for risk assessments.

Nevertheless, even at this time, a review of the Hazard Highlights at the 228 sites gives evidence in most cases that health risks, if any, will be confined to workers and others within installation boundaries and will not pose risks to the general population of the state.

The federal government is providing substantial funding for correction of past environmental problems at military bases. Included are sites of abandoned unexploded ordinance (e.g., Makua Valley) and other sites outside of existing installations (e.g., Kahoolawe). Investigation/remedial action to be carried out under these programs is expected to preclude any significant health risks to occupants of military installations, as well as to the general public. Likewise, investigation/remediation will be designed to preclude or mitigate any threat to ecosystems of importance in Hawaii. For example, at Schofield Barracks, drinking water supplies are contaminated with trichloroethylene above the maximum contaminant level (MCL). This water is treated by air stripping so that the tapwater is below the MCL.

Four Hazardous Waste Sites

Aiea Laundry site. Investigation of this site revealed contamination of soils with organic solvents, including tetrachloroethylene (PCE)and Stoddard solvent. DOH in 1990 requested a risk assessment study to determine risk from (1) ingestion of contaminated soils, (2) inhalation of contaminated soil particulates, and (3) inhalation of volatile organic vapors. A major concern associated with the site was an open section of fence between the laundry and an adjacent elementary school. Here, at least theoretically, children could come through the fence and play in contaminated soils. (DOH confirms that the fence has been fixed and a warning sign is now in place.) Using "worst-case" assumptions, the 1990 study concluded that individual lifetime risks from soil ingestion and inhalation were 10^{-6} or less. Excess cancer risk from inhalation of volatile organic compound (VOC) vapors was calculated to be 10^{-3} individual lifetime risk to children playing in the contaminated soils. Because this is a significant risk level, the assumptions used in the 1990 study were reviewed by the working group. The working group disagrees with the calculated risk reported in the 1990 study for the following reasons:

1. The "worst-case" exposure scenario assumed the children played on the contaminated soil for four hours a day, five days a week, 52 weeks a year, for five years. This is a highly unlikely exposure scenario upon which to base risk management. Although it is difficult to develop an average exposure scenario, the working group felt that this "worst-case" exposure assumption was high by at least one to two orders of magnitude. A more reasonable scenario could assume a child plays on the soil for 2-4 hours a week, 25 weeks a year (no school in summer, holidays), and for maybe one year. (No children were ever reported at this site.)

2. The concentrations of vapors inhaled by the children were determined from calculated soil area emission rates of VOC and modeled using a box model. Not only are dispersion models generally not applicable directly over the emission source of interest, but the box model was used inappropriately in this study. The box model assumes uniform mixing of pollutant and air within a meteorological "stable" region. The mixing height intended for use in the model is determined by the characteristics of turbulent dispersion in the atmosphere. The mixing height used in the report was the

height at which the contaminant was inhaled (1.13 meters). Inexpensive air sampling at the site could reduce uncertainty about the inhalation risk.

Given the problems with the risk assessment reviewed herein, the working group felt that the inhalation cancer risks are probably not significant for the few children who might have played intermittently on this site. The risk was ranked comparatively lower.

Kailua-Kona landfill. The Kailua-Kona landfill has been operating since the late 1960s and consists of about 30 acres of land one-half mile west of the community of Kealakehe on the Big Island. Since the early 1970s, the landfill has had a persistent problem of underground and open fires. As the waste within the landfill decomposes, landfill gas comprised of methane, carbon dioxide, nitrogen, oxygen, and small amounts of VOCs and hydrogen sulfide are generated. During dry periods, refuse and debris at the landfill ignite several times a month. County officials have alleged that some fires may be set deliberately or caused by careless use of cigarettes. Underground fire sporadically breaks through the landfill surface, causing a strong smell and heavy black smoke that drifts toward the town of Kailua. The DOH has received complaint letters from various parties (legislators, parents of children going to Kealakehe schools, residents of Kailua-Kona and Kealakehe). Inspection reports prepared by Hawaii County's environmental health sanitarian express concern about the recurring smoldering problems at the landfill. A major fire in May 1990 lasted for three days and caused the nearby school, police station, and part of the town to be evacuated due to the potential smoke hazards. In 1987, the U.S. EPA Region IX Emergency Response Section sent a team to assess the potential public health threat from these fires. The concentrations of chemicals measured in the smoke around the landfill are shown in Appendix G3. Average concentration of benzene measured at the landfill was about 10 mg/m^3 during the excavation of a landfill fire. A simple gaussian dispersion model of downwind concentrations from an area source indicates that the concentration of benzene 0.5 km from the landfill was over 200 ppbv.

If the downwind community were exposed to this concentration 6 days per year, 24 hours per day, for 20 years (the fires have already been burning intermittently for 20 years), the calculated individual lifetime excess of cancer risk is $2x10^{-5}$. Significant risk is confined to the population of 428 housing units in the vicinity.

Waianae used-oil dumps. As many as 2,000 drums of used oil have been illegally stored and dumped along the Waianae coast on Oahu. At least seven sites appear to have been identified as containing contaminated soils from leaking drums, which have the potential for human contact and exposure. Analytical data (Appendix F6) of random and directed samples from the oil revealed that total lead content in the used oil may be as high as 3,000 parts per million. Several oil samples revealed flash points below 140° F, characterizing them as flammable. Some samples revealed the presence of perchloroethylene. Unfortunately, no soil samples have been collected and analyzed to date. Pooling liquid wastes and soaked soils have been observed. There appears to be opportunity for direct contact, ingestion, and inhalation of contaminated soils by area residents. Children have been observed playing around the leaking drums. Some drums have been removed, and the contents of some leaking drums have been transferred to drums that are sound. Professional opinion of the working group is that there is significant likelihood of exposure to the contaminated soils; however, the severity of the exposure cannot be determined at this time. The DOH has received reports of uncontrolled burning of waste oil. Lead might be released to the atmosphere, which could provide another exposure pathway for nearby residents. The general public risk for exposure to used oil is low. However, due to the high lead content, the working group suggests that the risk to nearby resident children be ranked medium at this time, despite the lack of soil-specific concentration data.

Hilo Bay arsenic contamination. Wallboard made from bagasse was treated with arsenic compounds (for protection against termites) from 1932 to 1963 at a facility near Hilo Bay. The facility is now closed, the building was demolished, and a hotel was constructed in its place;

much of the ground is covered with asphalt. Arsenic (in the less toxic pentavalent form) is present in the soil and in sediments in the bay. No drinking water sources are downslope from the site. High volumes of groundwater (~2 million m^3/day) flow under the site to the bay. Measurements (reported in National Oceanic and Atmospheric Administration [NOAA] Preliminary Natural Resource Survey, 1990) indicate that arsenic is not bioaccumulating in fish or shellfish inhabiting the Hilo estuary in amounts that exceed Food and Drug Administration (FDA) action levels for food consumption. There appears to be no plausible scenario for human exposure. The site is, however, being evaluated by the Hazard Ranking System for inclusion on the National Priorities List for cleanup under the Superfund program. No data could be released to the HERR study regarding the "score" of the site. Risks to organisms and ecosystems may justify further study and possible remediation. A high HRS score does not necessarily imply a risk to human health.

HAZARDOUS MATERIALS

Underground Storage Tanks (USTs)

USTs can present a significant risk to human health and/or ecosystems if they leak and if human populations and/or valuable ecosystems are thereby exposed to hazardous contents in harmful concentrations.

The potential for unacceptable risks may be mitigated by the fact that the EPA has had stringent UST regulations for several years, as well as public education programs:

- to prevent leaks and spills,
- to find leaks and spills, and
- to correct the problems caused by leaks and spills.

There are over 5,500 USTs in Hawaii. Two-thirds of them are on Oahu. One-third are on neighbor islands in numbers roughly proportional to those islands' populations. Over 50% of those tanks contain gasoline, which is of special concern because it contains benzene, a carcinogen.

As of January 1992 there were 325 known leaking USTs in Hawaii. Almost 80% are on Oahu, with the remainder split evenly among Kauai, Maui, and Hawaii. The total of leaking tanks was about 100 in 1990, the number had doubled by 1991, and by August 1992 was 425. With only 2-1/2 DOH field personnel positions available for action on these 425 tanks, there has been understandable concern. As of December 1991, there had been no reported evidence of contamination from USTs in any drinking water supplies or potable aquifers. The potential for contamination of potable groundwater is minimized (but not eliminated) by the fact that many of the USTs on Oahu are in locations over caprock, where transport to the basal aquifer is not possible. It is understood that the most prevalent hazard from Hawaii USTs is from potential explosion of volatile organic compounds (A. Kabei, pers. com., 1992).

During the study period up to January 1992, it was not possible to assemble data (i.e., contaminant levels and exposure potential) for leaking USTs on which risk assessment could be based. Accordingly, this environmental problem area has been left unranked. The required data will likely be available before DOH begins its efforts on Risk Based Strategic Planning. At such time as DOH has staffing to adequately enforce the cited EPA regulations, residual health risks will, by definition, be "lower." Meanwhile, due to the ubiquity of potential risk, attention should be given not only to enforcement of UST regulations, but to the development of risk assessment data.

Multimedia Exposures to Lead

Since October 1990, after the enactment of Hawaii Administrative Rule, Title 11, Chapter 5, "Environmentally related illness and injury reporting," there have been ten reports received by the Office of Hazard Evaluation and Emergency Response (see Appendix F3). Only one of these, a case of acute lead poisoning, is classified as "confirmed." Because of renewed state and federal concern over lead, particularly in children, the working group on toxic exposure decided to concentrate on environmental risks associated with multimedia exposures to lead.

A recent review in the scientific literature detailed the state of current knowledge on lead exposures in Hawaii (Wiebe et al. 1991). Major sources of environmental lead exposures may occur through ingestion of contaminated soils, inhalation of airborne lead, ingestion of lead in drinking water, and ingestion of lead-based paints. Young children are particularly susceptible to adverse effects from exposures to lead, which include the potential for increased prevalence of motor and intelligence deficits. The 1990 report concluded that unacceptable lead exposures in Hawaii children were well below the national average. Two cases of lead-based poisoning in Hawaii children were reported, which were likely related to exposure to lead-based paints. Lead has been found in fish from Manoa Stream. Lead can be leached from ceramic ware where it is an ingredient of the glaze. Of particular interest in Hawaii is the contamination of water by lead in catchment water systems. Since the 1990 report was issued, a new action level for blood lead level has been set at 10 microgram/dL (deciliter) reduced from the previous level at 25 microgram/dL. Existing lead studies were reviewed in light of this new standard.

Of the entire group tested for blood lead levels on the Big Island (400 people), approximately 20% had blood lead levels higher than 10 microgram/dL (Maskarinec 1991). The approximate population using catchment systems is 12,000, suggesting that as many as 2,400 people on the Big Island may have blood lead levels higher than the currently recommended action level. A 1973 DOH study in Oahu's Kalihi Valley found a mean blood lead level of 17 microgram/dL in the 76 children tested. This value would likely be lower today due to the removal of lead in gasoline products and the resulting dramatically reduced lead burden in the environment since the 1970s. Although air monitoring in Hawaii for lead concentration under the NAAQS has never revealed lead concentrations of concern, a 1983 DOH study of lead exposures to children downwind of an H-1 freeway viaduct indicated that 33% of the children had FEP levels (an indicator of blood lead) higher than 35 microgram/dL, which could suggest blood lead higher than the 10 microgram/dL. The lead exposure could be due to re-entrainment into the air and ingestion of lead-contaminated dusts near the freeway. Further studies are needed to confirm the blood lead concentrations.

Decades of research have been conducted on health effects associated with lead exposure. Relative to most other environmental pollutants, the degree of uncertainty in estimating the health effects of lead is low. The adverse effects of inorganic lead and lead compounds on the neurobehavioral development of children may occur at lead levels so low that there is essentially no threshold (USEPA-Integrated Risk Information System 1991). There are sufficient animal data but inadequate human data to verify the carcinogenicity of lead, and it is classified as a B2 probable human carcinogen. Current EPA regulations allow 50 ppb lead in drinking water. However, new regulations have been proposed to set a goal of zero as a maximum contaminant level for lead in drinking water. Monitoring first-draw samples at the tap inside homes will be required of thousands of public water supply systems. The new U.S. regulation proposes that first-draw samples of drinking water from 90% of the homes sampled should have less than 15 ppb lead. The distribution of concentrations of lead in household drinking water in Hawaii is unknown at this time.

Since existing studies have demonstrated that high blood lead levels may exist in Hawaii's population, the working group determined that the risk from exposure to lead should be ranked <u>medium</u> for adults and comparatively <u>higher</u> for children.

<u>Accidents and Spills of Toxic Materials</u>

The number of reported spills of oil and hazardous substances increased from 162 incidents in 1989 to 312 in 1990. Over 83% of these incidents occurred on Oahu. Where the substance spilled was identified, 58.3% were petroleum products, 3.5% pesticides, and 2.9% ammonia (DOH 1990e). Spill reports do not consistently detail the exact nature of the chemical, the quantity spilled, or the exact location and type of release. Therefore, it is impossible to conduct a quantitative risk analysis using these data. The lack of significant population health effects suggests that the general population risks are comparatively lower at this time. However, the continued increase in the number of spills may be of concern. The working group determined that there were not sufficient data to assess the health risk to public groups near a toxic spill at this time.

The U. S. Coast Guard reported about 1,000 oil spills over the last three years. Only a very few of these were spills of significant volume. The risk from these spills appears to be primarily an ecological rather than a health risk. This risk is addressed in Part 2.

Risk Assessment Was Frustrated by Lack of Data

There is a paucity of analytical monitoring data both in air, water, and soils on which to base this preliminary health risk ranking. In all cases, DOH should rely less on screening models and more on well-designed investigations that include a sampling-and-analysis plan for measurement of toxic chemical concentrations in different media (soils, air, etc.) where contamination is suspected. Because of the complexity of evaluating environmental health risks, consultant reports should be reviewed by all appropriately trained staff (chemists, statisticians, geologists, atmospheric scientists, toxicologists, epidemiologists, etc.) before the significance of the health risks reported can be properly assessed and ranked. Transport modeling and population exposure analysis should be conducted subsequent to the sampling and analysis program to determine population risks. A coordinated effort by all DOH staff is necessary to develop a meaningful and successful risk-based strategy for establishing environmental priorities in Hawaii.

PESTICIDES

The risks of exposure to pesticides in drinking water or through eating contaminated seafood are discussed in Appendix E4. Pesticide stresses on ecosystems are discussed in Part 2. Household pesticides might pose a significant risk to health in the home environment as discussed in the section on "Indoor Air Pollution," based on mainland data but not yet confirmed in Hawaii.

Tests for residues of pesticides in food are conducted by the federal FDA and the state Department of Health (DOH). Random tests have detected residues in 3% of samples tested and no significant exceeding of tolerance (safe) levels has occurred. Certain "problem" crops, whether imported or produced locally, are tested more frequently. These crops, such as watercress and other vegetables, are removed from the market if tolerances are exceeded. In view of the above testing record, "residual" public health risk from pesticide residues on food in Hawaii is judged to be comparatively <u>lower</u>. Here, as in the case of water quality, DOH monitoring must be continued to effectively manage this risk.

The HERR study finds reason for concern, in general, about the past and current use of biocidal compounds in Hawaii. Rainfall, topography, and geology combine to move any long-lasting chemical that is placed on plants, soil, or exposed structures, into underground and surface waters. The ultimate destination of pesticides that do not biodegrade may be drinking water supplies or water bodies where bioaccumulation in aquatic organisms may occur. Proper application of approved or registered pesticides usually mitigates water contamination.

There are, however, actual and plausible instances of misuse:

- homeowners do not always read or follow label instructions
- spills and leaks occur in commercial applications during mixing and sprayer-loading
- improper disposal of containers, rinse water, or unused pesticides
- spray drift or leaching from target areas onto water courses

The growing body of information at the DOH from well sampling and the ability to model the behavior of chemicals in soil and underground water show that long-lasting pesticides, solvents, and other compounds are moving laterally and downward over much of Oahu, Maui, and Kauai, and on parts of the Big Island. Monitoring data are still inadequate for the necessary understanding of what happens when the toxic materials reach an aquifer: i.e., the direction, speed, and distance they travel, their longevity, and their concentration when they reach a well. A legacy of persistent pesticides and solvents from the past will continue to appear for 10-15 years in surface and underground water. There is no feasible way to stop this contamination, and so detection in and removal of pesticides from drinking water supplies will likely be necessary in additional wells in order to reduce the risk to public health. Eventually the aquifers should become free of contaminants, as hazardous compounds are banned from use and the older pesticides are degraded, leached out, and diluted. On the other hand, these contaminated sediments (e.g., as in Pearl Harbor) may persist in place for generations of time.

Overland flow of rainwater picks up pesticides and other toxic materials, either in solution or adhered to sediment particles. For example, chlordane, a termiticide placed in soil around buildings until the late 1970s, is found in Hawaii's streams and bays. This nonpoint source of pollution that includes carcinogens is a growing hazard in Hawaii.

Appendix E3 lists pesticides previously and currently used in Hawaii that are known or potential contaminants of ground and surface waters.

WATER PROBLEM AREAS

The HERR study examined four water-quality problem areas: drinking water, municipal wastewater, industrial wastewater, and nonpoint source pollution. These areas are interrelated. Water shortages, if they should occur, could exacerbate water-quality problems but this conjecture is not analyzed in this report. In many cases where water quality problems exist, the source of pollutants is not definitively known, and degradation may have resulted from a combination of sources or the cumulative effect of a number of pollution occurrences. Pearl Harbor and the Ala Wai Canal are examples of water bodies impacted by a number of human activities.

Health risks to the human population from contacts with fresh or marine waters were difficult to ascertain because of the generally good water quality in Hawaii. Few chemical contaminants are found in the water column because of their low solubility. Microbial contamination associated with pathogenic organisms is not often found in recreational waters used by the general public, except when spills of raw sewage occur. There are no accepted methods for determining contact-related health risks from exposure to low levels of microbial contamination. It is known that contact with sewage-contaminated water can result in skin diseases and/or gastroenteritis, however, there is no dose-response relationship to predict these illnesses. Furthermore, there is no epidemiological evidence in Hawaii on the incidence of these diseases. It is difficult to quantify health risk.

Various chemical contaminants in the bottom sediments of stream and marine areas may be taken up by fish and shellfish, which are ultimately consumed by community residents. As yet, there are only limited data available on these bottom sediments and possible bioaccumulation.

Drinking Water

Hawaii's drinking water has long been considered to be of especially high quality. In 1977, a spill of dibromo-3-chloropropane (DBCP) contaminated a well in Kunia. Ethylene dibromide (EDB) was also spilled in the same area. Both were found in soil and in wells as a result of a few large and numerous minor spills associated with a pesticide mixing-and-loading area. These discoveries gave impetus to continued monitoring for organic chemicals in groundwater, which has resulted in the identification of other contaminants.

Health risks from drinking water were first assessed at the tap, and no significant health risks were found. The potential health risk from drinking certain contaminated raw water supplies was then assessed to provide a basis for comparing risks of drinking treated and untreated water.

The study did not address the contamination of water sources that are utilized only for agricultural or industrial purposes. Data on contamination of those sources are relevant, however, in that they may indicate the vulnerability of Hawaii's drinking water sources and the resulting potential for human health risks.

Hawaii gets the great majority of its water, including drinking water, from groundwater sources. Typical volcanic islands produce a lens of freshwater at their base due to high infiltration of rain through the porous soil. Potential hazards to drinking water supplies are chemical and microbial contamination. The former results from industrial and agricultural activities, while the latter results from both domestic and animal wastes.

Modern analytical techniques can detect quite small amounts of contaminants. The following terms are used frequently in this section: parts per million (ppm) is equivalent to milligrams/liter (mg/L); parts per billion (ppb) is equivalent to micrograms/liter (micrograms/L); 1,000 liters = 1 cubic meter (m^3).

USEPA data in Appendix E3 list sources of groundwater contamination and possible health effects of those contaminants. From these data, the HERR team identified the following contaminants as hazards of concern in Hawaii:

Atrazine
Ethylene-di-bromide (EDB)
1,2 Dibromo-3-chloropropane (DBCP)
Trihalomethanes (includes chloroform, bromoform,
chloro-dibromomethane, and dibromochloromethane)
1,2 Dichloro-propane (DCP)
Carbon Tetrachloride
Nitrates
Trichlorethylene (TCE)
1,2,3 Trichloropropane (TCP)
Microbial contamination

The team then reviewed data from the following sources:

- DOH water quality monitoring data
- 1989 DOH Groundwater Protection Strategy (1990b)
- County Board of Water Supply data

- University of Hawaii Water Resources Research Center publications
- Hawaii Association of Sugar Planters (HSPA) water quality data
- Department of Agriculture Report to the Fifteenth Legislature, 1989 Regular Session: In Response to Section 46C of the Supplemental Appropriations Act of 1988 (report on pesticides in soil and ground water investigations)
- personal communications from individuals knowledgeable of this subject.

All the above data sources were used to identify hazards. For risk assessment, DOH water quality monitoring data for 1990 to 1991 was used for most contaminants. HSPA data for atrazine were used because of its high quality and HSPA's consistent monitoring since 1985. For EDB and DBCP risk assessment, DOH and Board of Water Supply data were used to determine risk at the tap. As no significant health risk at the tap was identified, Board of Water Supply data for treatment plant influent were used for risk assessment of raw water before treatment.

Population data were obtained from DOH files. The Board of Water Supply provided estimates of populations for systems with split service, or split distribution of supplies.

Data quality. Concentrations of the identified contaminants as used for risk assessment are generally reliable. Concentrations at or near the detection limits are less reliable due to inherent analytical limitations. Analytical error for detection limits in the parts per billion (ppb) and parts per trillion (ppt) range can be high.

Data that were considered unconfirmed or questionable by the collecting agency were not used.

Several of the organic chemicals presently detected in Hawaii's drinking water supply, including EDB, DBCP, trichloropropane (TCP), dichloropropane (DCP), dieldrin, hexazinone, and atrazine, are associated with pesticides used on pineapple and sugar cane fields.

Only atrazine is still in use, but residues of the others remain in the soil in many areas. Industrial contaminants detected in Hawaii's drinking water include trichloroethylene (TCE), carbon tetrachloride, EDB (also used as a fuel additive), and tetrachloroethylene (PCE).

Dieldrin, hexazinone, and PCE are not found consistently and then only in barely detectable levels, well below standards. Hexazinone exhibits no known human health effects. TCP was not assessed because, though considered a carcinogen, cancer slope factors and health effect models are not yet available.

Table 1-7 presents HERR estimates of potential exposure to hazards of concern. Risk assessments and discussion of these potential exposures are presented in the following pages.

In conducting risk assessment, DOH and EPA standards were assumed to be sufficient to protect human health. In cases where contaminant concentrations in raw water (which might someday become a source of drinking water) were as high as 50% of the standard on a consistent basis, the data were examined for trends that might indicate future standard exceedances. If such were noted, risk assessment was conducted. Risk assessment was also conducted for those sources that are known to be contaminated but are currently treated before delivery.

The volatile organics EDB, DBCP, PCE, and TCE found in raw water supplies are <u>not</u> detectable in the treated water. PCE found in water at Hawaii Volcanoes National Park results from the interior paint coating on the rainwater catchment tank. Individual risk is low and it is understood that the Park Service is removing the existing coating.

Few data are available on private water supplies and home catchment systems. Lead can be leached from roofing materials by acid precipitation near the volcano, thus contaminating catchment water. All drinking water systems with 15 hookups or serving 25 persons or more are monitored by DOH.

<u>Cancer risk assessment.</u> Cancer risk was calculated according to standard EPA procedures, utilizing the Hawaii standard exposure assumptions included in Appendix D5. The entire population served by

Table 1-7
Potential Exposure to Hazards of Concern

Part A
Raw Water

Contaminant	Potentially Exposed Communities	Population
Atrazine	Pepeekeo	1,500
TCE	Schofield	28,500
	South Kohala	
EDB	Waipahu	NA*
DBCP	Mililani	26,500
DCP	Kunia	10,500
Nitrates	Kunia	10,500
Tetrachlorethylene (PCE)	Volcano National Park	??
Microbial Contamination	All raw sources exposed to contamination by influence of surface water, pipe leak, etc.	NA
Carbon Tetrachloride	Wahiawa	23,000

Part B
Treated Water

Trihalomethanes	Upper Kula (possibly Makawao)	4,500
	South Kohala	11,000

* Treated water is frequently distributed to different areas for varying durations of time. According to Hawaii Board of Water Supply, it is not possible to accurately ascertain the population specifically served by the Waipahu wells, since water from the Waipahu wells goes to different areas at different times.

a water system was assumed to be exposed. This is a conservative assumption, because many communities are served by more than one source. The risk assessment used EDB and DBCP concentrations in raw water (i.e., the influent to the treatment plants).

The risk assessment, summarized in Table 1-8, indicated individual risks less than 10^{-6} for all potentially exposed communities except Waipahu. The cancer risk from EDB in the raw water at Waipahu is slightly higher than the de minimus level of 10^{-6}, but the water is treated with activated charcoal to reduce contamination at the tap in order to meet standards. This confirms the risk assessment conducted by a consultant in 1985 (Environ Corporation 1985). The treatment actions taken then by DOH and the Board of Water Supply in response to the EDB and DBCP contamination are seen to be quite conservative.

Trihalomethanes (THMs) are the only examples in which water treatment creates a contaminant in drinking water. They are formed during chlorination when the free chlorine reacts with organic materials in the raw water. Therefore, they are generally found in drinking water supplies that use surface water. THMs (e.g., chloroform) are carcinogenic compounds. The risk of their presence must be balanced against the risk of bowel disease resulting from the presence of pathogenic organisms in untreated surface and some ground waters. The standard for THMs allows for quarterly averaging. Thus, single samples may exceed the MCL of 100 ppm, but consistent exceedances are not permitted. Two communities in Hawaii are exposed to concentrations of THMs that occasionally approach state and EPA standards: South Kohala on Hawaii and Kula on Maui. Using chloroform as a surrogate for THMs and recent average amounts detected, the cancer risk to individuals in these communities was calculated to be 1.5×10^{-5} and 1.2×10^{-6}, respectively. The MCL was not exceeded, however.

Health effects other than cancer. The contaminants producing non-cancer health effects that are found in concentrations in untreated water in Hawaii that are sufficient to warrant a risk assessment include nitrates, atrazine, carbon tetrachloride, TCE,

Table 1-8
Potential Cancer Risk from Drinking Untreated Water

Contaminant	Maximum Contaminant level (MCL) (ppb)	Raw Water Concentration (1) (ppb)	Daily Intake (2) (mg/kg-day) Average	Cancer Potency Factor (CPF)	Excess Individual Risk	Exposed Community	Exposed Population	Annual Excess Cancer Incidence in Population
Atrazine	3	1.69	4.76E-06	2.22E-01	1.1E-06	Pepeekeo	1,358	1.5E-03
Carbon Tet.	5	0.95	2.68E-06	1.3E-01	3.5E-07	Wahiawa	23,170	8.1E-03
TCE	5	18.2	5.13E-05	1.1E-02	5.6E-07	Schofield	28,662	1.6E-02
PCE	5	5.13	1.45E-05	5.1E-02	7.4E-07	Volcanoes Park	(7)	
EDB-Mililani	0.02	ND		8.5E+01		Mililani	26,530	
-Waipahu	0.02	0.055	1.55E-07	8.5E+01	1.3E-05	Waipahu (6)	NA	
-Kunia	0.02	ND		8.5E+01		Kunia (6)	10,460	
DBCP-Mililani (4)	0.04	0.052	1.47E-07	5.0E+01(3)	7.3E-06	Mililani	26,530	1.9E-01
-Waipahu (5)	0.04	ND		5.0E+01		Waipahu (6)	NA	
-Kunia	0.04	0.009	2.54E-08	5.0E+01	1.3E-06	Kunia (6)	10,460	1.3E-02

<u>Assumptions:</u> The risk assessment for drinking water utilized the following assumptions:

- o standard Hawaii exposure assumptions were used for all exposure scenarios
- o calculation of the hypothetical cancer risk of drinking <u>untreated</u> water used an exposed population equivalent to the actual population served by the specific drinking water distribution system mentioned, unless otherwise noted
- o state and USEPA standards were assumed adequate to protect human health

<u>Notes:</u> 1) Average of available data depending upon length of time of samplings; not less than one year.

2) Daily ingestion is assumed as 1.6L; exposure duration 9 years; exposure frequency 350 days/year

$$\text{Intake=(mg/kg-day)} = \frac{\text{Chem. conc. *ingestion rate*exposure frequency*exposure duration}}{\text{body weight(70kg)*averaging time (70yrs*365 days/yr)}}$$

3) The CPF for DBCP is EDB CPF X 0.59. This is based on best EPA judgment; IRIS.
4) No EDB is detected at Kunia. 0.2 parts per trillion is the detection limit.
5) No DBCP is detected at Waipahu; 0.2 is the detection limit.
6) Population based on entire Waipahu-Ewa-Waianae system.
7) Transient population, probably consistently 4,000.

chloroform, and PCE. Table 1-9 summarizes non-cancer risks from drinking untreated water. Microbial contamination also poses a risk if disinfection systems fail or nontreated systems become contaminated. DOH records show no significant bacteriological quality violations have occurred, and therefore no risk assessment was conducted. Data on raw water quality are limited because system operators and DOH are only required to ensure bacteriological quality of water in the distribution system.

Nitrates are of particular concern in infants and young children because of "blue baby syndrome" (infant methemoglobinemia). The data on wells at Kunia show a trend of increasing nitrate concentrations approaching drinking water quality standards. The average concentration over the past year was 6 ppm. The EPA and DOH standards are 10 ppm.

Risks calculated for non-cancer health effects are summarized in Table 1-9.

Future monitoring needs. The HERR study indicates much of Hawaii's groundwater contamination is the result of historical, not present, use of organic chemicals. Major contaminants now found (EDB, DBCP, and TCP) are no longer in use. Models have suggested that the concentrations of EDB and DBCP in central Oahu groundwater should peak in the mid-1990s (Lau 1991) and will decline to nondetectable levels early in the next decade. Atrazine levels in water supplies, along with its application procedures, are closely monitored by the HSPA. HSPA is also researching different compounds to replace or use in combination with atrazine for some applications. Its use has been discontinued in certain areas of Pepeekeo to prevent further contamination of water supplies in that area. Other contaminants, such as TCE and carbon tetrachloride, are now closely monitored. These risks can continue to be managed by DOH and the County Boards of Water Supply, and practices can be established to prevent further contamination of the water supplies.

In Hawaii, only the treated water systems have a continuous time series of water-quality data. Influent to existing treatment plants is a mixture from a variety of wells and depths. Influent

Table 1-9
Non-Cancer Risks from Drinking Water Contaminants

Contaminant	MCL (ppb)	Average Drinking Water Concentration (ppb)	RfD (mg/kg-day)	Daily Intake(1) (mg/kg-day) Average	Hazard Index Intake/RfD Average(2)	Exposed Community	Exposed Population
Nitrates (3)	0.01	0.0061	1.00E+00	4.18E-08	4.18E-08	Kunia (4)	10,460
Atrazine	3	1.69	5.00E-03	3.70E-05	7.41E-03	Pepeekeo	1,358
Carbon Tet.	5	0.95	1.30E-01	2.08E-05	1.60E-04	Wahiawa	23,170
TCE	5	18.2	1.00E-02	3.99E-04	3.99E-02	Schofield	28,662
Chloroform (5)	100	70	1.00E-02	1.53E-03	1.53E-01	Upper Kula	4,724
PCE	5	5.13	1.00E-02	1.12E-04	1.12E-02	Volcano Park	?

Notes: 1) Daily ingestion is assumed as 1.6L; exposure duration 9 years; exposure frequency 350 days/year

$$\text{Intake}=(\text{mg/kg-day})=\frac{\text{Chem. conc. (ppm)*ingestion rate*exposure frequency*exposure duration}}{\text{body weight (70kg)*averaging time (9 yrs*365 days/yr)}}$$

2) When the hazard index is less than one, which is the case with all of these contaminants, the risk is considered acceptable and public health is protected.
3) Nitrate RfD is based on no observable effect level (NOEL) for human infants; ingestion rate is adjusted for children under 6 to 0.5L/day (EPA Survey, 1984; EPA Risk Assessment Guidelines).
4) Refers to Kunia section of system; Village Park is the probable affected community.

Child intake Conc.*0.001*0.5*350*6/(15*6*365)
Adult intake Conc.*0.001*1.6*350*9/(70*9*365)

5) Chloroform serves as a surrogate for total trihalomethanes since an RfD for total trihalomethanes is not available.

RfD = Reference dose

water-quality data provide no information on quality of water from individual wells; nor do they provide data useful for the assessment of contaminant migration in aquifers.

The great depth of groundwater, and high costs of monitoring (analyses, personnel, and well installation) have hampered increased information gathering. Increased monitoring efforts and the use of data from existing wells in conjunction with pumping data are necessary to provide adequate understanding of the extent of contamination and potential migration.

Communities experiencing higher THM levels are currently undertaking studies to reduce their formation during chlorination. Efforts to date have included treatment with chloramines and use of coagulating agents to reduce the level of organic matter in the raw water.

In summary, the health risks from drinking water are in the lower category. The present levels of contamination demonstrate the susceptibility of water supplies to contamination. Potential health effects and public concern require careful continued monitoring.

Industrial Wastewater

There is relatively little industrial pollution in Hawaii compared to mainland states. The Navy industrial complex at Pearl Harbor, including the Shipyard Supply Center, Submarine Base, Public Works Center, and Naval Station, together with the adjacent Hickam Air Force Base and lesser outlying military installations on Oahu, constitute the major industrial-type facilities in the state. The nonmilitary types of industrial facilities that produce point-source wastewater discharges are petroleum refinery operations, electric power plants, and sugar cane processing. Light industries such as boat and auto repair facilities also discharge wastewater, some of it being nonpoint surface runoff.

Major pollutant constituents of industrial wastewater are inorganic wastes that cause chemical oxygen demand (COD) and organic wastes that cause biochemical oxygen demand (BOD), effecting dissolved oxygen; total suspended solids (TSS); ammonia; oil and grease; and nutrients (nitrogen and phosphorous). A few of the discharges also contain metals such as iron, copper, and chromium, and heated water.

It is difficult to distinguish risks associated with industrial wastewater discharges from risks due to other causes of water quality degradation. Hawaii has a limited number of industrial facilities. Surface water quality problems are largely due to nonpoint sources, or, in some cases, the cumulative effect of multiple point sources (e.g., Pearl Harbor).

The discharge of industrial pollutants is regulated by the following federal and state laws:

- Federal Clean Water Act
- Federal Safe Drinking Water Act
- State Water Pollution Control Act
- State Safe Drinking Water Act
- State Water Code

The Federal Clean Water Act and the State Water Pollution Control Act closely parallel one another in providing for the control of pollutant discharges into waters, for setting water quality standards, and for establishing policies of nondegradation. The state Act applies to all waters of the state, including groundwater, while the federal Act applies to all navigable waters. The Federal Clean Water Act provides guidelines for water quality standards. State standards are more stringent than these guidelines for most conventional parameters of water quality (Liu 1992). State toxic standards are set at the federal guidelines for most parameters. For regulatory purposes, waters of the state are classified by their physical characteristics and by their beneficial uses.

Both of the Drinking Water acts deal with the discharge of industrial pollutants through the establishment of the Underground Injection Control (UIC) program, limitations on location of facilities, and the application of drinking water standards to certain effluents.

The Water Pollution Control Act established a state equivalent of the National Pollutant Discharge Eliminations System (NPDES) permit program for the monitoring of industrial discharges and enforcement of discharge standards.

Hawaii's UIC program regulations are under Title 11, Chapter 23 of the Administrative Rules. The regulations, which include a permit program, were established in 1984. The UIC permit program is relatively new, and there are estimated to be between 3,000 and 5,000 wells potentially under these regulations. DOH files on the NPDES and UIC programs were the primary sources of data for risk assessment of environmental problems due to industrial wastewaters. Information was also obtained from the 1990 State Water Quality Plan (DOH 1990d) and the City and County of Honolulu Water Quality Management Plan (Department of Public Works 1990).

<u>State NPDES Program.</u> The state currently has 79 NPDES permits. Permitted facilities are classified by a ranking system as major or minor, depending on the size and type of facility and its discharges. The most significant characteristic is quantity of flow, which when in excess of 0.5 million gallons per day (MGD) denotes a major industrial facility. The state also classifies these facilities as agricultural, industrial, or municipal (domestic wastewater).

Of the 79 NPDES facilities in Hawaii, 24 are major: 12 municipal, 8 industrial, and 4 agricultural. Approximately 50 percent of the NPDES permits include zone-of-mixing permits that allow for a specified area of the receiving waters to exceed water quality standards. These zones of mixing are generally permitted for the following parameters: temperature, nutrients (nitrogen and phosphorous), and TSS.

The discharge permits specify which pollutants are to be monitored in effluents and in receiving waters. Allowable limits are based on the type of effluent, likely pollutants, and quality of the receiving water, with the policy of nondegradation as the goal. Monitoring reports indicate <u>no substantial violations</u> of NPDES requirements that would affect human health. Violations noted were for exceeding limits of TSS, temperature, and, less frequently, nutrients.

"Nondischarge" permits allow for the emergency discharge of effluent from surface lagoons or self-contained treatment facilities, or for runoff from facility grounds in the event of a 25-year return, 24-hour storm. While no comprehensive data are available, it appears that some facilities with "nondischarge" permits often have had discharges more frequently than the occurrence of the storm magnitude in the permits. These facilities are required by the regulations to report all discharges. For example, Meadow Gold Dairies, near Waimanalo, has recently been fined by DOH for illegal discharges of raw manure from overflowing holding ponds into Inaole Stream.

Whole effluent toxicity testing requirements, under development for the last two years, were incorporated into some permits in 1991. Toxicity standards require 80% survival of two chosen aquatic species in 100% effluent for 7-day chronic testing and 48- and 24-hour acute testing. To date, no permits with the whole effluent requirement have had any violations.

In 1987 and 1989, the Wahiawa sewage treatment plant experienced difficulties that were caused by Diazanon. The source of this toxic contamination was never determined. Illegal dumping was suspected.

Monitoring of wastewater discharge facilities is accomplished through inspections and reviews of required monthly discharge reports. Major facilities are inspected annually, while minor facilities are inspected at least once during their five-year permit, usually biennially.

<u>No human health hazards were identified</u> in this assessment of industrial wastes. Recreational uses of some receiving waters have been limited by water quality degradation from a combination of point and nonpoint sources. Human health effects are impossible to quantify as yet and are potentially most likely to be seen in the ingestion of contaminated fish or marine products. The extent of bioaccumulation of contaminants has not been well-investigated. Past waste management practices have resulted in contaminated bottom sludges (e.g., Ala Wai Canal and Pearl Harbor). Risks from such contamination cannot be evaluated due to a lack of data.

Underground Injection Control Program. Types of UIC wells permitted in Hawaii as classified by federal regulations include stormwater and industrial drainage, aquaculture wells, untreated sewage, septic systems, cooling water return flows, industrial disposal, and other nontoxic material wells. This last category currently has two subtypes in Hawaii, swimming pool drains and experimental wells for injection of waste similar to aquaculture wastes.

The exact number of UIC wells in Hawaii is not known. According to DOH personnel there are some 3,000 wells with permits. A report by Engineering Enterprises Inc. (1987) for the EPA recorded 617 permitted wells and discussed the types of wells found in Hawaii. It is expected that there are a number of wells, particularly domestic waste and dry wells, not yet identified.

Analytical data identifying the pollutants in the injection fluid are sparse, and testing has only recently been required by the state, so a quantitative risk assessment is not possible. The risk from UIC wells can be qualitatively discussed in relation to the types of wastewaters injected. Industrial injection fluids potentially contain solvents, oil and grease, solids, heavy metals, and bacteria. Aquaculture and agriculture wells may contain high levels of nutrients, solids, organic chemicals (pesticides), BOD, and bacteria. Pollutants of concern from wells injecting domestic sewage include pathogenic bacteria, nutrients, grease, and synthetic organic compounds.

Little information is available on the migration of these injected wastes. Presumably, they are injected into underground waters of limited beneficial uses. They may or may not be treated through natural processes and are eventually transported into the ocean.

Potential health risks and ecological risks of these injected fluids cannot be evaluated due to the limited information available. The primary health risk is the transport of pathogens or chemical contaminants to private water supplies. This may occur between UIC wells and private drinking water wells, both of which may yet be unidentified. The ecological risks associated with UIC wells involve the migration of contaminants to surface waters. These contaminants may have toxic effects or may otherwise stress aquatic ecosystems (e.g., nutrients may create algal blooms).

Findings. Public health risk from industrial discharges has been judged to be in the lower category. Pollution of marine and freshwater sediments and possible subsequent contaminant uptake by marine organisms that are used for food may contribute health risks to certain limited consumer populations.

Facilities may choose UIC well permits over NPDES discharge permits because UIC well permits require less stringent standards and monitoring. This wastewater management strategy may lead to increased pollution problems.

Industrial discharges contribute to lower water quality in a number of water quality limited segments. Currently, however, the locations in which industrial discharges appear to play a greater role in water quality degradation are not areas of preferred recreational use (e.g., Pearl Harbor and Honolulu Harbor).

The potential risk to ecosystems is evaluated in detail in Part 2.

Municipal Wastewater

Effective municipal wastewater collection, treatment, and effluent disposal is well-recognized as an essential component of public health and environmental protection. Assessment of the health and ecological risks associated with deficiencies in municipal wastewater collection, treatment, and disposal systems is complex. It involves (1) identifying collection systems defects, (2) assessing effectiveness of treatment processes, (3) identifying system components that may cause risk, (4) determining the affected areal extent of contaminants, and (5) distinguishing impacts of municipal wastewater from those of other pollutants.

It is essential to differentiate among various sources of the identified hazards. That is, if sewage-related water quality degradation is primarily due to collection system leaks, then upgrading a treatment plant is irrelevant.

In Hawaii, it is especially important to consider the hazards associated with effluent discharged through UIC wells. As discussed in the industrial wastewater section, fluids injected into UIC wells are not monitored to determine their pollutant characteristics. The fluids may be discharged via underground channels into nearby surface waters, particularly in the geology of the younger islands.

Collection systems. Much attention is given to the performance of a wastewater treatment plant, while less notice is usually given to the performance of a collection system. The collection system is critical to ensuring that the sewage is transported to the plant for proper treatment. Failure of the collection system usually results in direct discharge of untreated sewage to the environment. This is obviously a public health hazard, the degree of which depends on the amount of sewage discharged and the duration of the discharge.

Unplanned, uncontrolled spills and bypasses from the Oahu sewerage system have become increasingly common. There were approximately 75 wastewater spills in 1991 (compared to 26 spills in 1990, 22 in 1989, and 12 each year from 1986 to 1987), according to a DOH summary. While no large system can be expected to perform without some disruptions, the number of spills experienced by the Oahu system was sufficient to warrant enforcement action by the EPA and DOH. The EPA has ordered the City and County of Honolulu Department of Public Works to develop complete spill prevention plans for each of its facilities. Data on the collection systems associated with wastewater treatment plants (WWTPs) on other islands were not obtained, but the DOH did not indicate any significant problems with these systems.

Nondetected leakage both into and out of wastewater collection system piping (i.e., infiltration and exfiltration) is more difficult to assess. It is important because of the potential for exfiltration to contribute to nonpoint source pollution, and infiltration impacts on hydraulic loading of the treatment system. Standard engineering practice designs sewer lines to be normally less than full. The reason for this design practice is to ensure that if there are any joint leaks (a common occurrence), groundwater will normally flow into the sewer rather than wastewater flowing out to the groundwater.

Heavy hydraulic loads on existing systems in Hawaii suggest that infiltration into sewer pipes may be extensive, which can cause operating problems at the plant. On the other hand, when there is exfiltration, backfill materials commonly used around sewage collection lines serve to filter many of the contaminants out of the wastewater and thus mitigate pollution potential. Studies should determine if any major outflows are occurring.

Assessment of wastewater treatment and disposal. A description of different levels of wastewater treatment and an analysis of environmental risks posed by different treatment levels are described in detail in Appendix E1. This HERR study concludes that for major wastewater treatment plants on Oahu with outfall disposal, there are no significant risks to health from existing treatment methods when operating properly.

Disposal by outfall. There are a total of 15 (12 major and 3 minor) municipal WWTPs in the state of Hawaii. Eight of the major facilities are on Oahu, two on Maui, and one each on Hawaii and Kauai. Most of these plants discharge directly into the ocean. Two plants on Oahu discharge into the inland Wilson Reservoir. Several plants, including Kailua-Kona, Kohala, Lahaina, and Poipu, discharge to groundwater via UIC wells.

Prior to the establishment of the EPA in 1970 and the increased concern for marine water quality, collected sewage in Hawaii was discharged untreated into the ocean via shallow outfalls. As understanding of public health and environmental impacts increased, changes in the level of treatment, location, and depth of discharge were made.

Significant improvements in embayment and coastal water quality in the last two decades resulted from relocating the Sand Island outfall to deep water, extending and relocating the Kaneohe outfall, constructing the Honouliuli outfall, and prohibiting zones of mixing for wastewater outfalls in embayments (such as Kaneohe Bay, which has limited exchange with the open ocean) in accordance with the state water quality standards. This prohibition recognized that the exchange rate (flow into and out of an area) and related residence time are the most important factors affecting embayment water quality. Another important study found that characteristics and activities of watershed areas strongly affect water quality in embayments but not in open coastal areas, where the speed of the alongshore current and the degree of turbulence (wave action) are determining factors.

In Hawaii there are now two municipal wastewater ocean outfalls over 200 feet deep (Sand Island and Honouliuli), two that are over 100 feet deep (Waianae and Mokapu), and several others that discharge in shallower waters (Hilo, Sandy Beach, Port Allen, Fort Kamehameha).

To meet DOH and EPA requirements, a number of special studies and routine monitoring programs have been conducted on several ocean outfalls in Hawaii: Sand Island, Honouliuli, Mokapu, Sandy Beach, and Hilo. These studies were undertaken to determine if additional treatment or other improvements were necessary to protect public health and the environment. Another study of the Mokapu outfall serving the Kailua-Kaneohe WWTP is currently in progress and has already provided a further understanding of the dynamics of effluent dispersal (see below).

Underneath a mixed zone, which varies in depth according to weather, season, and climate, ocean water temperature decreases and its density increases with depth. Studies have repeatedly shown that tidal currents and seasonal temperature variations combine to provide density profiles in coastal regions of the Hawaiian Islands that make surfacing of plumes from deep ocean outfalls (Sand Island and Honouliuli) infrequent events (Edward K. Noda, pers. com., February 28, 1992).

The average currents are parallel to the shore and do not transport submerged plumes toward the shore. During the Kona season, onshore winds do transport the plume shoreward but it seldom reaches the shore. Surfacing occurs more frequently in the winter when there is less of a temperature gradient.

The 100-ft deep outfall plumes (e.g., Mokapu) surface as often as one-half of the time, while shallower outfall plumes (e.g., Sandy Beach) surface most of the time. In all cases the plumes are highly variable due to wave-induced pulsing and eddies in the water column. Plume thickness is generally about 30% of the vertical rise distance.

As the treated sewage emerges from the outfall pipe deep in the ocean, it is rapidly mixed with seawater. Dilution increases as the plume rises due to the buoyancy of the lower density effluent, which is mostly freshwater. Dilution (mixing) decreases the density difference between the plume and the surrounding seawater until the densities are equal; then the plume stops rising and disperses laterally with prevailing currents at that depth. Most of the time with deep outfalls, the warmer surface water layer is lighter than the mixed plume, and no surfacing occurs. Plumes that do surface are more diluted because they have risen over a longer distance and time, which provides more opportunity to entrain ocean water. A plume that surfaces is composed of from hundreds to thousands of parts seawater to one part sewage effluent.

When a plume surfaces, currents and winds must direct it to coastal recreational waters if it is to pose a threat to public health. Studies have shown that currents do not generally transport the plumes to Hawaii's coastal recreational areas. Floatable material is mostly removed by treatment and, if any remains, moves (sails) downwind generally independent of the underlying current. Local wind-induced transport affects the upper 5 meters or so of the water column. The top 1-2 meters go generally downwind and the next 3-4 meters move either counter to the wind or at some angle. This pattern is modified on the windward side of Oahu where, because of wind set-up in the nearshore area, the wind-induced transport is diverted parallel to the shoreline. Present treatment methods minimize floatables found in WWTP effluent. This fact, in conjunction with the primary wind characteristics, produces a low likelihood of these floatables reaching the nearshore recreational areas (about 0.1% of the time from Sand Island, Noda 1992).

Further dilution occurs as the mixed effluent moves either on the surface by wind action or in the subsurface by currents. The result is that if any effluent does reach the shore, it is diluted several thousand times from the concentration at the outfall. Die-off of pathogenic organisms during mixing and transport also serves to lower risk to public health.

In the ongoing study of the Mokapu outfall, dye tracer was used to follow plume transport. Plumes did not reach the coastal areas under any of the conditions studied (Krock 1992). (See Appendix E for details.) Earlier studies using mathematical models predicted that organism transport to the nearshore area would result in water quality meeting DOH standards. The organism transport from the outfall is at least two orders of magnitude less than the coastal nonpoint source (surface drainage) related contribution. The model estimated that at Kailua Beach Park the likelihood of a contaminant being from the outfall is 1/100th the likelihood of it being from the land.

At the Kapaa-Waialua outfall, water quality characteristics are dominated by freshwater inflows that carry sediment, nutrients, and coliform. Hilo Bay water quality is also greatly affected by nonpoint sources and freshwater inflows. The WWTP is not considered the major contributor to water quality problems in Hilo Bay.

In summary, these studies of tidal dynamics, current, and wind on the effluent from WWTPs on Oahu show that there is no evidence of deep outfall effluent transport to coastal recreational areas. The Mokapu outfall effluent for the Kailua-Kaneohe WWTP is also not transported to the nearshore areas. The smaller, shallow outfalls in Hawaii have not been as thoroughly studied, and water quality problems may be expected from some transport to nearshore areas. Any consequent risks to human health are difficult to estimate because of the lack of exposure data and dose-response relationships. An indicator organism or test for pathogens of human origin is needed.

The outfall-related studies have also provided information on the chemical and biological characteristics of the coastal receiving waters. The most significant finding for human health is that the municipal wastewater generated in Hawaii does not contain significant quantities of toxic metals or other chemical toxins (Krock 1992).

Nutrient loading and consequent oxygen depletion that may occur in embayments do not appear significant for open coastal outfalls in Hawaii due to the short residence times and large dilution rates.

There is no indication of oxygen depletion at any of the open coastal outfalls, with or without secondary treatment.

The biological/ecological results of these studies indicate that the direct effect of open coastal discharges is limited to the immediate area of the diffuser ports. The studies have not shown evidence of the buildup of organic material in the general benthic area. There is an increase in the fish population along all outfalls. This is attributable primarily to an enhanced habitat and secondarily to a greater food supply. In shallow water outfalls (e.g., Sandy Beach) there is an increase in the coral growth rate and in the population density of sea urchins.

Disposal of domestic wastewater by UIC wells. The use of UIC wells for the disposal of municipal wastewater has not been studied sufficiently to determine its influence on coastal water quality. Impacts are site specific, and will vary dependent upon local geology. Should the injected fluid be transported with the local groundwater and reach embayments and other nearshore areas, significant water degradation can result.

UIC wells are used for large treatment plants in Lahaina, Kahului, Kailua-Kona, Kihei, Eleele, and several small plants in small communities and hotels. There are over 300 domestic wastewater injection wells in Hawaii. The UIC wells for hotel wastewater are particularly common for resort areas in Maui and the Kohala coast on the Big Island. For example, the Maui Algae Task Force of DOH has made a preliminary finding that treated sewage injected into four wells at Lahaina is migrating to nearshore waters and is contributing to accelerated growth of algae and seaweed; that, in turn, adversely affects coral reefs, snorkeling, diving, and swimming.

The UIC wells are installed away from known drinking water supplies. It is possible, however, that the discharge may contaminate future water supplies or unidentified private wells. Again, little data are available to assess the likelihood of contamination.

The ease of obtaining a UIC permit and adherence to its minimal monitoring requirements may appear attractive to WWTP owners, compared with the more rigorous NPDES process. Other existing UIC wells used for WWTP discharges should be studied (as at Lahaina) to determine their impact on groundwaters and coastal water quality so that a proper risk assessment can be conducted.

<u>Health risks from WWTP effluent.</u> Recent studies have demonstrated that little of the routine discharge through deep outfalls from Oahu wastewater treatment plants is carried to nearshore areas used for recreational purposes (Roger Fujioka, pers. com., 1992). Coliform counts at the beaches originate primarily from landward nonpoint sources. The die-off rates of enteric bacterial and viral organisms in Hawaiian marine waters are much more rapid than in temperate marine waters or freshwater. Effluent transport studies, water quality data, and the nonviability of sewage-related pathogens in Hawaii marine waters form a rational basis for a qualitative risk assessment: human health risk from the discharge through deep outfalls of treated municipal wastewater from existing Hawaii treatment plants is considered to be in the <u>lower</u> category.

Accidental sewage spills and discharges have lowered water quality and caused potential short-term health threats on a number of occasions in the past year. The health threats have been to recreational users of marine waters and have not affected drinking waters. The health risk endpoints associated with recreational contact are gastrointestinal infections, skin infections, and skin rashes. These have not been observed in Hawaii's epidemiological statistics, although unreported incidents may occur. The health risks are reduced when affected areas are posted with warnings.

It is important to preface a discussion of health risk assessment associated with bacterial pollution with comments on the indicator organism concept, reliability of association with health outcomes, and difficulties in determining epidemiological associations.

Indicator organisms may or may not mean pollution from human waste. In Hawaii's tropical climate, the accepted standard indicator organisms (enterococci) occur naturally in soil and in other animals as well as in human waste. This creates difficulties in determining the specific source when indicator organisms are detected. While efforts have been made, no suitable indicator organism to replace the enterococci has been accepted.

There is also no dose-response relationship between low level concentrations of indicator organisms and disease. Numerous epidemiological studies have attempted to quantify the links between bathing in sewage-polluted waters and health effects. The studies have produced dissimilar results and have failed to confirm a consistent dose-response relationship (Cabelli 1989). Many diseases contracted via ingestion when bathing in contaminated waters can also be contracted readily from eating adulterated foods. The tracing of such infections is extremely difficult.

Consequently, it is not possible to quantify actual health risks from bathing in contaminated waters by using specific measurements of indicator organisms. Qualitatively, it is assumed that health risks do exist where bathers are directly exposed to waters actually contaminated with untreated sewage. For this reason, DOH closes beaches when a sewage spill into nearshore areas occurs.

The low levels of indicator organisms routinely found in Hawaii recreational waters and the caveats regarding indicator organisms yield the conclusion that health risk from pathogens in Hawaii marine waters is in the lower priority category.

The large number of unplanned discharges and spills from the collection system poses some risk to public health. This risk is reduced when the affected areas are closed, which changes the exposure from one of involuntary risk to voluntary risk. Nevertheless, there is an undesired potential exposure to sewage-contaminated waters. People enter the water even when it is posted. DOH-ordered beach closings on Oahu totaled 22 days in 1990 and 93 days in 1991. The human health risk in the managed spills where beaches are closed is considered in the lower category because it is not the routine condition. The waters are reopened after bacteriological testing confirms the absence of high levels of the indicator organism.

These continuing spills and accidental discharges have adverse impacts on quality of life, ecosystems, and the economic welfare of the tourist industry.

Municipal wastewater discharge to UIC wells has the potential for both health and ecosystem risk. The data available at present are only sufficient to indicate potential risk. Ecosystem effects from UIC well discharges are only now being studied by DOH and others.

Nonpoint Source Water Pollution

Water quality in Hawaii is generally considered to be excellent. The majority of the nearshore waters meet water quality standards that are the most stringent in the nation. All oceans, bays, estuaries, lakes, and streams support their designated beneficial uses. The state does, however, have 14 water quality limited segments. As defined by EPA, a water quality limited segment is a body of water (in Hawaii these are bays, estuaries, harbors) that fails to meet one or more of EPA's water quality standards, even with complete control of all point sources of pollution (i.e., the pollution comes from nonpoint sources).

Overall risk from water quality degradation is discussed in this section since much of urban nonpoint source pollution is collected at and discharged from point sources such as storm sewers. It is difficult to establish all specific sources of local water quality degradation. Point sources of pollution alone do not appear sufficient to produce the degree of water quality degradation present in some segments.

Nonpoint source pollution varies with the type of land use. Its destination and contribution to the receiving water will depend on topography, vegetative cover, erodibility of soil, stream characteristics, and the presence or absence of buffers (e.g., wetlands). Sediment, nutrients, metals, organic chemicals, toxic metals, and pathogens are common constituents of urban runoff. Agricultural areas are likely to have runoff containing high sediment levels, nutrients, and pesticides. Residential areas may contribute a range of constituents including sediment, nutrients, metals, household pesticides, used oils, and pathogens. Industrial areas commonly contribute petroleum products, metals, and organic compounds. The constituents of Hawaii's runoff have not been completely inventoried.

Water quality monitoring capabilities are limited by personnel and budget resources. Analysis costs are high, particularly for toxic and hazardous materials. Consequently, total nitrogen, total phosphorous, total coliforms, and turbidity are the only parameters routinely monitored. In many areas of the state this may be sufficient, but certain water quality segments require more in-depth study to define water quality management needs.

The following sections provide an overview of Hawaii's water quality and nonpoint source pollution in Hawaii.

Water quality and nonpoint source pollution. Water quality degradation in Hawaii, where it occurs, is evidenced by increased concentrations of sediment (suspended solids), nutrients (nitrogen, phosphorous), and coliforms or enterococci (microbial contamination indicator organisms). Other pollutants associated with nonpoint sources, such as toxics and petroleum products, are also occasionally found in the water column. Sediment, nutrients, and toxics are discussed in the island-by-island analysis.

Hawaii has set its standards for the microbial contamination of recreational waters at 7 colony-forming units (CFU)/100 ml, the strictest standard in the United States. The EPA standard is 35 CFU/100 ml. Violations of the state standard are infrequent except for certain man-made drainage areas and harbors such as the Ala Wai Canal and Kahului Harbor. Monitoring frequency is, however, inadequate to detect many violations which, when they occur, are usually associated with heavy rainfall, which sweeps sediment and trash, and leaches chemicals from soil, into receiving waters.

Leptospirosis, a naturally occuring bacterial parasite, is common in many of Hawaii's freshwater streams. This parasite (hosted in a number of animals) can cause illness in human beings, and in rare cases it is potentially fatal if not treated. It is not studied in detail in this report because its presence is not associated with pollution from human activities.

Ciguatera refers to a toxin found in certain algae that are eaten by Hawaiian reef fish. The poison accumulates when reef fish are eaten by larger fish and then may effect human consumers of the larger fish. There is a controversy about whether ciguatera occurs more frequently in coastal waters that have been degraded by human activity such as dredging, construction, or pollution. There are no data or cause-effect mechanisms to allow a calculation of risk of ciguatera poisoning from such distrubances of the marine environment. It may be a natural hazard, unconnected to human activity.

The Ala Wai Canal is an example of man-made drainage water bodies in the state that are nonswimmable due to pollution. These waters do support aquatic life, but the Ala Wai Canal should not be considered fishable because of high levels of pesticides found in fish tissues there. A preliminary risk assessment for dietary intake of fish from the Ala Wai Canal was completed as a part of this study and is discussed below and in Appendix E4.

Incidences of lowered water quality have occurred on Oahu episodically as a result of heavy rainfall, sewage plant bypasses, and other sewer system-related spills. Problems associated with municipal sewage collection and treatment are discussed in greater detail in the Municipal Wastewater section.

Basic sources of water quality information are DOH, state Department of Land and Natural Resources (DLNR), City and County of Honolulu Department of Public Works (1990), and the U.S. Soil Conservation Service.

Statewide summary of nonpoint source pollution. According to DOH's nonpoint source assessment report (1991), the major nonpoint source pollutants are sediment, nutrients, toxics, and pathogens. Major sources are from agricultural, urban, industrial, and military land uses. Major impact areas (segments) are bays and estuaries and coastal areas where streams empty into the oceans.

Sediment. A 1978 DOH estimate (Technical Committee on Non-Point Source Pollution Control 1978) reported the following totals of sediment generated per island:

	tons/year
Kauai	294,000
Molokai	215,000
Maui	207,000
Hawaii	183,000
Lanai	138,000
Oahu	103,000

The rate of sediment generation from cropland was estimated at 14 tons/acre/year. In 1982, 58,800 acres of land cultivated in Hawaii were identified as "highly erodible." Most of this land was planted to sugar cane and pineapple. Sugar cane land was reported as less erodible than pineapple land.

The economic effect of sedimentation is illustrated by the plans of the U.S. Army Corps of Engineers in fiscal year 1990 to remove approximately 1 million cubic yards of sediment from Honolulu, Hilo, Kahului, Nawiliwili, and Pearl harbors at an estimated cost of $5.75 million. The disposal of these contaminated sediments poses other risks.

Erosion and sedimentation are natural processes but in Hawaii are exacerbated by human activities. Enforcement of applicable regulations to reduce erosion and sediment delivery is inadequate.

Nutrients, toxics, and pathogens. No statewide or island data are available for these pollutants from nonpoint sources, but, as discussed in detail below, these pollutants are significant in specific bays and estuaries.

Table 1-10 summarizes data on Hawaii's water quality limited segments. Oahu has the largest number (eight) of water quality limited segments (polluted from nonpoint sources), followed by Kauai with three, and one each for Hawaii, Maui, and Molokai.

Hawaii. Hilo Bay is the only water quality limited segment on the island of Hawaii. The contributing watershed, 60% in agricultural land, represents about 10% of the island's area. However, the wet coast of Hawaii, from Hilo north to Upolu Point, including the Hamakua coast (about 15% of the island), experiences considerable erosion and consequent coastal sedimentation, resulting in adverse effects on coral growth (USEPA 1989).

Kauai. The three water quality limited segments in Kauai-Hanapepe, Nawiliwili, and Waimea bays--have tributary watersheds that cover about one-fourth of Kauai's land area. All three

Table 1-10
Water Quality Limited Segments: State of Hawaii

SEGMENT	AREA (ACRES)		LAND USE (% APPROX.)			POLLUTANTS					MAJOR USES AND VALUES OF SEGMENTS			SUMMARY COMMENTS
	Segment	Watershed	Agricul.	Forest	Urban	Turbidity/ TSS	Nutrients	Heavy Metals Pesti- cides	Litter Solids	Pathogens	Ecosystem	Recreation	Economic	
HAWAII														
1. Hilo Bay	1,788		60	25	—	X	X	X			X	X	X	(15% land use is lava) Class A embayment
KAUAI														
1. Hanapepe	297	17,300	50	50	—	X					X	X	X	Class A embayment
2. Nawiliwili	333		45	45	10	X	X				X	X	X	Class A embayment
3. Waimea	1,214	57,000	30	70	—	X					X	X	X	Class A embayment
MAUI														
1. Kahului	242		60	—	40	X	X			X	X	X	X	Class A embayment
2. Lahaina		4,920	22	69	9	X					X	X		Class A embayment
MOLOKAI														
1. S. Molokai	11,417		60	40	—	X	X				X		X	Class AA and A waters
OAHU														
1. Honolulu Harbor	1,775	7,000	—	45	55	X	X	X	X	X			X	Class A embayment
2. Kahana	294	5,300	—	95	5	X	X				X	X		Class AA embayment
3. Keehi Lagoon	3,550	10,200	—	50	50	X	X		X			X	X	Class A embayment
4. Kewalo Basin	10	4,000	—	40	60	X	X	X	X				X	Class A embayment
5. Pearl Harbor	5,100	92,600	35	40	25	X	X			X	X	X	X	Special Classification
6. Waialua-Kaiaka Bay	1,208	70,700	38	56	6	X	X				X	X	X	Class AA and A embayments
7. Ala Wai Canal	12	10,400	—	50	50	X	X	X	X	X		X	X	Class A embayment
8. Kaneohe Bay	11,939	25,600	—	60	40	X	X			X	X	X	X	Class AA embayment

embayments are classified as Class A marine waters, and all have important ecosystem, recreation, and economic values. Sedimentation is the major environmental problem; health risks are minimal.

In addition, Hanalei River and Harbor, classified as Class AA marine waters, have been cited as being under development pressure, although nonpoint source pollution is not yet a problem.

Maui. The only water quality limited segment on Maui is Kahului Harbor, where the watershed comprises only about 5% of the island's area. This is classified as Class A, with a tributary watershed that is 40% urbanized and 60% agriculture (sugar cane). Sedimentation, excess nutrients, and pathogens are major pollutants. Commercial shipping and recreation are major uses of the harbor, although there are some ecosystem values.

Although not listed as a water quality limited segment, Lahaina Harbor is adversely affected by sedimentation and turbidity after heavy rainfall and runoff, primarily from sugar cane agricultural lands (22% of watershed) and urban areas (9% of watershed). Economic losses associated with recreational use of the harbor have been experienced, and coral reefs have been damaged.

Molokai. The entire south coast of Molokai is listed as a water quality limited segment. More than one-half of the coast is classified as Class AA marine water. Its tributary area comprises more than one-half of the entire island area. Sedimentation is the major problem, caused by erosion from the dry agricultural (60%) and forest (40%) lands. Feral animals are an important cause of erosion. Sedimentation threatens the integrity of the coral reefs.

Oahu. Nine water quality limited segments are listed on Oahu. Four of these are in urban Honolulu--Ala Wai Canal, Kewalo Basin, Honolulu Harbor, and Keehi Lagoon. These are classified as Class A marine waters, with heavy commercial and recreational use and with heavy pollution loads.

The fifth segment on the Leeward coast is Pearl Harbor, which has a water area of 5,100 acres and a watershed of 92,600 acres (almost one-fourth of the entire area of Oahu). Sedimentation and nutrients are major pollutants coming from agricultural lands (35%), forest lands (40%), and urban areas (25%). Pearl Harbor has intensive military activity, recreational uses, and ecological values. It carries a classification as a special marine water.

Two Class AA segments are on the Windward coast--Kaneohe Bay and Kahana Bay. The ecological and recreational values of Kaneohe Bay are at risk from sedimentation, nutrients, and perhaps toxic chemicals and pathogens from the urbanized area (40% of the watershed). Kahana Bay, with a watershed that is largely forested, suffers from turbidity and excess nutrients, largely from natural causes.

Waialua and Kaiaka bays on the North Shore suffer from sedimentation and excess nutrients, caused by erosion from the 70,000-acre watershed, 38% of which is in agricultural use and 6% in urban use. Waialua Bay is classified as a Class AA marine water. Recreational use of the beaches is impaired by turbidity at times during the rainy winter months, and coral formations are adversely affected.

In addition to pollution at the nine segments, other coastal areas are adversely affected by turbidity and bacteria during periods of heavy rainfall and runoff. Included are beaches in Kahala, Waimanalo, Kailua, and the Windward coast from Kaneohe to Kahuku Point.

Risk to ecosystems. By its very nature, nonpoint source pollution impairs ecosystem values. However, in heavily urbanized areas such as Honolulu, natural ecosystems on land no longer exist and ocean systems are artificial (e.g., Honolulu Harbor, Keehi Lagoon, Kewalo Basin, and Ala Wai Canal). The as yet relatively undegraded natural ecosystems at high risk are Class AA marine waters such as Kaneohe and Waialua bays that are under development pressure. Other Class AA marine waters such as part of south Molokai and Kahana Bay are at less risk from development pressures.

The third category of ecosystems are those in Class A marine waters, such as Hilo Bay, Hanapepe, Nawiliwili and Waimea Bay, Kahului and Lahaina, part of south Molokai, and Pearl Harbor, which still have significant ecosystem values but are at considerable risk from development pressures. See Part 2 for a detailed analysis.

Health risks. Health risks associated with lowered water quality due to nonpoint sources include infectious diseases and a number of disorders due to toxic chemicals. Toxics may bioaccumulate in the food chain and have their greatest human health effect through ingestion of seafood. Domestic waste (sewage) causes gastrointestinal infections; eye, ear, and skin infections; and disorders of the upper respiratory tract.

There is no plausible scenario of exposure of the general population to chemical pollution in Hawaii waters. There are few data on the level of chemical contamination in bottom sediments. Toxics and heavy metals have been identified in sediments in the Ala Wai Canal and in fish tissue samples taken from the canal. Chlordane, dieldrin, and lead have also been reported in the biota and sediments of Kaneohe Bay. Monitoring data for industrial point sources in Hawaii show no evidence of toxic discharge. Any toxic contamination that may be present is likely from historical uses or present nonpoint sources. The levels of other organic chemicals in the sediment or their uptake by aquatic life has not been well studied. Such studies are expensive and do not fall under routine monitoring programs.

Risk assessment was conducted for a hypothesized special population that consumes fish caught in Ala Wai Canal. The assessment assumed a susceptible population ingesting large quantities of fish each day. The contaminants assessed included chlordane, dieldrin, and heptachlor epoxide. High additional individual risks of contracting cancer were calculated (see Appendix E4). This warrants prohibiting fishing in the canal and increased monitoring to determine the extent of similar pollution problems in other areas such as Kaneohe Bay.

Uncertainty. In most water quality limited segments there is a high degree of uncertainty both about the extent and nature of pollution and about the sources and pathways of some of the pollutants, especially heavy metals, nutrients, and pathogens. There is a dearth of recent data for most segments--much of the data and analyses are over 10 years old. Recently DOH decided to concentrate its surface water quality monitoring efforts on the water quality limited segments of nearshore waters. DOH monitoring data for the years 1986-91 have been included in this report on each segment, where available.

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PART 2

RISKS TO ECOSYSTEMS

PART 2

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INTRODUCTION

LITERATURE REVIEW

From a review of the literature, there is general agreement that the objective of comparative environmental risk assessment (as applied to ecosystems) is to rank a comprehensive set of environmental problems relative to one another into broad groupings of risk and to target response actions toward those geographical areas at greatest risk (Barnthouse et al. 1982, 1986; Cairns and Orvos 1990). Environmental risk assessment is still a developing field and comparative ecological risk assessment is even more so (see USEPA 1990; Rejeski 1991). The U.S. Environmental Protection Agency (EPA) and the Oak Ridge National Research Laboratory have sponsored conferences, reports, and research to foster a consistent approach for ecological risk assessment (USEPA in press a, b, c, 1986, 1991; Worden and Hegner 1991; Roybal 1991; Barnthouse et al. 1986; Hunsaker et al. 1989). Still there is no established or accepted standard procedure for comparative ecological risk assessment (CERA).

Several approaches have been used in the past, and all have advantages and disadvantages (see Cairns and Orvos 1990).

- Reductionist ecological methods: These attempt to compartmentalize ecological processes and effects into a myriad of understandable units and linkages. Generally these lack, and do not allow, evaluation of synergism. An example is tracking the flow of nutrients from their sources through the ecosystem. Quantification of the flow is possible, but drawing implications about effects at the regional level is complex. Reductionist approaches are useful in defining how individual stressors affect individual species and (sometimes) ecosystems, and how they can be detected and monitored. With two or more stressors operating on the same system, the analysis and interpretation become increasingly more difficult.

- Bottom-up methods: These rely on the use of models and laboratory data to quantify biological and ecological processes and impacts, primarily at the species and community levels. This can be useful at site-specific locations, but extrapolating the results to ecosystem and regional levels is more difficult, especially if two or more ecosystems and stressors are involved.
- Top-down methods: These evaluate structural and functional changes at the ecosystem and regional levels and are most easily applied where there is large-scale homogeneity in both the ecosystem and the stressor that affects it. Conversely, these methods break down when a region is a mosaic of many stressors and ecosystems. Normally there is a lack of sufficient data from a broad region to allow quantification.
- "Practical" methods: A recent review (Worden 1991a) recognizes the need to design and accomplish practical comparative ecological risk assessments useful to decision-makers, politicians, and nonscientists. To meet this goal, CERA need not be quantitative, and it may actually be preferable to keep it qualitative. A combination of best professional judgement and systematic evaluation of risks from available information is pursued. Effective communication to decision-makers is accomplished through use of maps, simplified scoring systems, clearly defined evaluative criteria, and a manageable set of ecological stressors. Defining the specific problem areas and classifying the ecosystems of the study region are important early steps in this approach to CERA.

The ecological component of the Hawaii Environmental Risk Ranking (HERR) project is more closely aligned to the last approach. The literature recognized several steps to environmental risk assessment (see USEPA 1986; Cairns and Orvos 1990): identifying the ecological hazards or problems, assessing the exposures, estimating the responses, and characterizing the risks. However, environmental risk assessments (with heavy emphasis on public health) differ from CERA in several significant ways (USEPA 1991; in press a, c; and others):

- CERA must consider the effects beyond just the individuals of a single species;
- No single set of ecological values and tolerances apply to all of the various types of ecosystems;
- Stressors are not only chemicals or hazardous substances--they also include physical changes and biological perturbations; and
- For public health purposes, all humans are treated equally, but with ecosystems some sites and types are more valuable and vulnerable than others.

Accommodating for these factors adds steps to comparative ecological risk assessments and renders them more subjective. The literature suggests the following steps should be included in CERA:

- <u>Ecological classification</u> - organizing the variability of the ecosystems into a set of categories, each with different responses to stressors;
- <u>Selection of stressors</u> - defining the observable sources of human-induced (anthropogenic) stresses to ecosystems and screening out those not relevant to the region or ecosystems under analysis;
- <u>Selection of "endpoints"</u> - defining the desirable attributes or characteristics of ecosystems (structure and function) that are damaged or jeopardized by the stressors and the degree of damage that is considered to be significant;
- <u>Evaluative criteria</u> - defining the properties of the ecosystem characteristics, values, and responses that can be measured and that determine the severity and frequency of impact from stressors;
- <u>Risk assessment</u> - applying the criteria on a site-by-site basis to determine the risk to each ecosystem occurrence, based upon data and judgement; determining the stressors most at fault and ecosystem types most at risk; and

- Risk ranking - comparative evaluation of the assigned risks among all the ecosystem occurrences (sites) in order to assign priorities for future action.

UNIQUE REQUIREMENTS FOR HAWAII'S ECOLOGICAL RISK ASSESSMENT

Hawaii offers other distinctions and characteristics that influence the emphasis and scope of a CERA.

- Hawaii is a small island state - No point in the state is more than 29 miles from the sea. People and all natural ecosystems live in close proximity to one another. All ecosystems are close to humans and are inherently more vulnerable.
- Hawaii has extreme climatic and habitat diversity - Climates range from alpine near the peaks of its highest mountains (approaching 14,000 feet in elevation) to temperate, subtropical, tropical, humid, and arid. Its marine ecosystems are tropical.
- Hawaii is geologically young - The main islands of Hawaii are less than eight million years old. The largest island (Hawaii) is less than one million years old. Earthquakes, lava flows, tsunamis, tropical storms, and heavy wave action have exerted major influences over ecosystem evolution and development in the islands.
- Hawaii is geographically and biologically isolated - As a consequence, many unique species of animals and plants have evolved both on the land and in the sea. Many of these are found nowhere else on earth and have never been exposed to the threats of aggressive plants and animals occurring outside Hawaii. Alien species, especially, are a significant threat to native species.
- Hawaii is "paradise" to many people and cultures - The mild climate, beauty, uniqueness, and diversity of Hawaii, especially its native ecosystems, have attracted many people to the islands and will continue to do so. There are intense pressures to accommodate more and more visitors and residents

to Hawaii, which in turn result in the encroachment of people, housing, resorts, and golf courses into fragile native ecosystems.

- Hawaii's mix of economic and industrial development - Agriculture, ranching, tourism, and military activities are more important in Hawaii than other types of economic development. These in turn pose a unique set of risks to Hawaii's ecosystems.
- Hawaii's ecological and conservation research - Because Hawaii is small and has attracted a number of ecologists, many of its ecosystems have been studied and evaluated. The HERR study was fortunate in being able to rely on well-informed experts and existing evaluations, and to integrate them into the ecological risk assessment.

METHODOLOGY

Risks to ecosystems are based on the values of actual sites around the state and the probability that stressors from human activities will significantly degrade these values in the near future. The ability of the ecosystem occurrence (site) to recover is also considered. Just as the individual human being is the focus of health risk assessment, the individual ecosystem site is what must be evaluated in this component of the HERR study.

Ecosystems are bounded biotic communities in interaction with their physical surroundings of energy, air, water, minerals, and soil (and also other ecosystems). The HERR study assessed only natural, essentially undeveloped ecosystems and thus excluded urban and agricultural areas that are substantially modified. We divided the Hawaiian island landscapes and near-shore waters into twenty-nine different natural ecosystem types ranging from the ocean to mountain peaks. The occurrences, or sites, of each terrestrial ecosystem type were recorded using data supplied by the Hawaii Heritage Program of The Nature Conservancy of Hawaii, U.S. Fish and Wildlife Service, Office of State Planning Geographic Information Service, State Commission for Water Resource Management, Hawaii Fishpond Study, Department of Land and Natural Resources, the Bishop Museum, the U.S. Army Corps of Engineers Coastal Resource Atlases, National Marine Fisheries Service, Department of Land and Natural Resources Division of Aquatic Resources, and National Oceanic Atmospheric Administration Coastal Atlas for Oil Spill Response.

Procedure for Ranking

1. Establish the Ecosystem Classification - defining and selecting a manageable number of ecosystem types that are identifiable (mapable) through currently available databases and reports, and categorized by biophysical properties (elevation, vegetation, salinity, etc.).
2. Inventory Ecosystem Occurrences (Sites) - gathering data concerning the location, resources, degree of disturbance, and level of protection. Previous studies and personal interviews formed the basis for the inventory; no new studies were conducted for HERR.
3. Develop Criteria of Value for Each Ecosystem Type - determining individual criteria for the components of value for each of the different ecosystem types, on the basis of data sets available, previous valuation studies, measurable attributes, and changes to those attributes which degrade the resources.
4. Estimate Value of Each Ecosystem Occurrence - assigning numerical scores to each site on the basis of four components of "value": biodiversity/biological resources, recreational resources; cultural/esthetic resources; and economic productivity. The uncertainty of the rating of each component was recorded.
5. Develop Stressors List - determining what consequences of human activities cause unwanted, negative impacts on natural ecosystems.
6. Gather Stressors Data and Estimate Risk - collecting information on past, present, and near future human activities that impact the specific ecosystem sites chosen

for this study. Environmental experts estimated the frequency and severity of damage from stressors to each site with which they were familiar. Their uncertainty was also recorded.

7. Map Information - creating map overlays of geographic information relevant to sites, location, boundaries, values, and stressors. Many map "layers" are used to illustrate geographic attributes, such as native forest distribution, rare or endangered species habitat, historic/cultural sites, alien species distribution, public recreation areas, concentrated fisheries, whale density areas, etc.
8. Rank According to Risk - comparing a site's overall priority score, which is the product of a site's value score and total risk score. Such scores can be used to establish priority for future action.

ECOSYSTEM CLASSIFICATION

Considerable attention was devoted to developing an ecosystem type classification for the HERR project. Based upon evaluation of other systems used for water quality, coastal resources, and vegetation in Hawaii, a composite draft classification was devised, reviewed, and revised. At a workshop held at the East-West Center in December 1991, a group of 20 leading ecologists from Hawaii further reviewed the classification in detail and recommended additions, deletions, and modifications. The marine types were further refined at follow-up meetings. During data analysis and compilation, additional minor changes were made.

On land, the ecosystem types were subdivided on the basis of elevation/climatic zones (e.g., alpine, subalpine, montane, lowland, coastal), vegetation/ground cover (forest, scrub, herb and grasslands, fernlands, aeolian), water bodies (streams, ponds, lakes, reservoirs, and wetlands), salinity (freshwater, anchialine, hypersaline, estuaries), rainfall or humidity (wet, mesic, dry), and subterranean types (lava tubes and caves). Marine ecosystems were subdivided on the basis of the type of coral reef (fringing, barrier, and non-reef), emergent vegetation (mangrove), shoreline features (beaches, fishponds), and offshore ecosystems. All of the categories are natural ecosystems, and all but two are native. Mangrove swamps in Hawaii are dominated by alien species of trees brought from outside Hawaii during the past century. Fishponds were constructed by the early Hawaiians during the past millennium. Intensively managed ecosystems (agriculture, plantation crops, orchards, agroforests) and urban areas were omitted from the HERR study because they are simplified and degraded relative to natural ecosystems. Ranking of stressors was concentrated on those natural ecosystem sites that have important values (a combined component score of 6 or more).

The ecosystem types used were:

1. Important offshore oceanic areas: the pelagic and benthic zone, including circulation eddies, 2-20 nautical miles from shore.

2. Important nearshore oceanic areas: ocean areas excluding coral reefs, to 2 nautical miles from shore; including dredged or man-made areas.

3. Offshore islets: smaller vegetated islands separated by open water from any of the eight main Hawaiian Islands.

4. Barrier reef: offshore shallow coral reef (at a depth of less than 3 m), separated from a main island fringing reef by a deeper lagoon; includes the lagoon and associated lagoon (patch and pinnacle) reefs to a maximum depth of 60 m.

5. Fringing reefs: a coral reef structure composed of corals, coralline algae, and other reef organisms; includes a shallow reef flat at depths less than 3 m and a deeper offshore area to a maximum depth of 60 m.

(6. This number was not used in the final categorization.)

7. Streams: natural waterways including the scoured stream bed and associated riparian vegetation; includes perennial, interrupted, and intermittent streams.

8. Estuaries: zones of characteristically brackish waters in well-defined basins or within the terminal reach of streams and with a continuous or seasonal surface connection to the ocean that allows

migration of marine and freshwater biota; the zone where ocean and freshwater mix, forming layers of freshwater overlying marine waters.

9. Mangrove swamps: a forest of emergent vascular vegetation growing in marine waters or adapted to marine salinities; a marine wetland dominated by trees; in Hawaii the dominant vegetation consists of alien species.

10. Fishponds: coastal structures enclosing water, built by the early Hawaiians, in which fish or other aquatic organisms were raised or harvested. Includes all fishponds with early Hawaiian built walls but not natural holding ponds or anchialine pools.

11. Coastlines: the shoreline or interface between land and sea, including ocean features influenced by the land and terrestrial features influenced by the sea; offshore limit is mean low tide, and the onshore limit is the vegetation line and associated sand berms.

12. Anchialine pools: open brackish waters with tidal action but no visible surface connection to the sea; includes pools on the surface and subterranean brackish aquatic systems.

13. Freshwater lakes and reservoirs: open water bodies on land with no appreciable salinity (less than 0.05 parts per thousand); including reservoirs, which are man-made lakes.

14. Hypersaline lakes: a lake with a prevailing salinity that exceeds that of normal seawater (salinity 40 parts per thousand or higher).

15. Wetlands: swamps, marshes, or bogs dominated by saturated soils and emergent vegetation, adapted to periodic-to-regular surface water inundation.

16. Coastal herb and grasslands: areas influenced by sea spray (within ca 30 m or 100 ft); dominant vegetation low-lying, not woody, includes forbs, herbs, cryptogams, small ferns, grasses, or sedges.

17. Coastal shrublands: areas influenced by sea spray (within ca 30 m or 100 ft); dominant vegetation shrubs (woody, less than 2 meters height, multibranched at 1-meter height; includes woody vines).

18. Coastal forests: areas influenced by sea spray (within ca 30 m or 100 ft); dominant vegetation trees (woody, greater than 2 meters height, generally single-boled at 1-meter height).

19. Lowland herb and grasslands: areas in a generally frost-free zone (ca 30-900 m or 100-3000 ft elevation); dominant vegetation low lying, not woody, includes forbs, herbs, cryptogams, small ferns, grasses, or sedges.

20. Lowland dry shrubland: areas in a generally frost-free zone (ca 30-900 m or 100-3000 ft elevation); dominant vegetation shrubs (woody, less than 2 meters height, multibranched at 1-meter height).

21. Lowland dry and mesic forests: areas in a generally frost-free zone (ca 30-900 m or 100-3000 ft elevation); up to 100 inches annual rain, or prevailing dry to moist, but not wet soil conditions; dominant vegetation trees (woody, greater than 2 meters height, generally single-boled at 1-meter height).

22. Lowland wet forests and shrublands: areas in a generally frost-free zone (ca 30-900 m or 100-3000 ft elevation); more than 100 inches annual rain, or prevailing wet soil conditions; dominant vegetation trees (woody, greater than 2 meters height, single-boled at 1-meter height; includes tree ferns) or shrubs (woody, less than 2 meters height, multibranched at 1-meter height; includes larger ferns, and mat-forming ferns or woody vines).

23. Montane dry and mesic forests: areas in an infrequent frost zone (ca 900-1800 m or 3000-6000 ft elevation); up to 100 inches annual rain, or prevailing dry-to-moist soil conditions; dominant vegetation trees (woody, greater than 2 meters height, generally single-boled at 1-meter height).

24. Montane wet shrublands and forests: areas in an infrequent frost zone (ca 900-1800 m or 3000-6000 ft elevation); more than 100 inches annual rain, or prevailing wet soil conditions; dominant vegetation trees (woody, greater than 2 meters height, single-boled at 1-meter height; includes tree ferns) or shrubs (woody, less than 2 meters height, multibranched at 1-meter height; includes larger ferns, and mat-forming ferns or woody vines).

25. Montane dry and mesic shrublands: areas in an infrequent frost zone (ca 900-1800 m or 3000-6000 ft elevation); up to 100 inches annual rain, or prevailing dry-to-moist soil conditions; dominant vegetation shrubs (woody, less than 2 meters height, multibranched at 1-meter height).

26. <u>Subalpine grasslands and shrublands:</u> areas in a frequent frost zone (ca 1800-2700 m or 6000-9000 ft elevation); dominant vegetation low-lying grasses, sedges, or shrubs (woody, less than 2 meters height, multibranched at 1-meter height).

27. <u>Subalpine dry forests:</u> areas in a frequent frost zone (ca 1800-2700 m or 6000-9000 ft elevation); less than 50 inches annual rain, or prevailing dry soil conditions; dominant vegetation trees (woody, greater than 2 meters height, generally single-boled at 1-meter height) or shrubs (woody, less than 2 meters height).

28. <u>Alpine desert and shrubland:</u> areas in a treeless, frequent frost zone (over 2700 m or 9000 ft elevation); vegetation lacking, very sparse, or shrubs (woody, less than 2 meters height).

29. <u>Lava tubes and caves:</u> subterranean tubes, cracks, or caves formed in lava, with associated plants and animals (including invertebrates), but excluding aquatic biota.

30. <u>Aeolian or early successional:</u> new lava flows with sparse or no vegetation, dominated by invertebrates and supported by wind-borne debris; or first-growth plant communities on early lava flows or cinder, often dominated by lichens and ferns, but also including flowering plants with increasing age of substrate.

A revised, condensed list of ecosystem types is recommended for the additional work needed to complete this project:

1. Ocean waters and bottom areas
2. Offshore islets
3. Coral reefs
4. Streams
5. Estuaries
6. Fish ponds
7. Coastlines
8. Anchialine pools
9. Lakes and reservoirs
10. Wetlands
11. Coastal vegetation areas
12. Lowland levels and grasslands

13. Lowland dry/mesic shrublands and forests
14. Lowland wet shrublands and forests
15. Montane dry/mesic shrublands and forests
16. Montane wet shrublands and forests
17. Subalpine shrublands and forests
18. Alpine desert and shrublands
19. Lava-associated ecosystems

SITE VALUATION

Each occurrence was rated (on a scalar of 1-3) as to its value to the people of Hawaii on the basis of four equally weighted components:

- Biodiversity/Biological Resources. The degree to which the site contains rare or endangered species of plants and animals; the condition or disturbance of native natural systems, fisheries, whale density areas; and unique biological resources.
- Recreation. Extent and variety of recreational opportunities (camping, hiking, hunting, swimming, diving, fishing, beach and park activities).
- Cultural/Esthetic Features. Archeological and historic sites; religious and special family places; exceptional natural beauty; importance to native Hawaiians.
- Economic Productivity. Goods and services provided from the site that have direct benefits (harvest, tourism revenues, fish catch) or indirect benefits (shoreline protection, groundwater recharge).

Some values can also be considered stressors. For example, the extensive recreational opportunities at Hanauma Bay on Oahu increase that site's value, while bringing crowds that stress the basic resource assets. This conflict is especially apparent at coastal sites. The HERR methodology allows consideration of both the beneficial and stressing factors of human activities when assessing risk.

A "reality check" of professional judgement was used to supplement available data, since many of the sites have been personally visited by members of the HERR team.

COMPONENTS OF SITE VALUE

A set of criteria for assessing the importance of each site were developed and then applied during the risk-ranking exercises for all of the site occurrences of each ecosystem. The criteria reflect the optimum attributes of each ecosystem and the change in attributes which degrade the ecosystems and increase the significance of the risk. In other risk-ranking projects elsewhere in the country, the analogous concept is the endpoint (Suter 1990; Hegner 1991a, b). The Hawaiian ecological risk assessment elevated the importance of an "endpoint" concept by adding, as a separate step, the valuation of each site occurrence based upon a set of properties or attributes that were compared against evaluation criteria for that particular ecosystem type. Table 2-1 lists the high, medium, and low value criteria for each ecosystem type.

Properties and attributes of importance to marine ecosystems included concentrated fisheries, high density areas for whales, sea turtle and monk seal feeding areas, seabird feeding areas, recreational areas, high coral and limu (edible seaweed) areas, and shellfish beds. For estuaries, important attributes included recreation, sites used for migration by endemic stream life and waterbird habitat. For fishponds, value is based on the degree of cultural or historic importance and integrity, potential for use as mariculture, and habitat for endemic waterbirds. For coastlines, important criteria included nesting and resting areas for seabirds, sea turtles, monk seals, presence of endemic or rare species, recreational or economic importance, and the presence of natural biological communities. For wetlands, the importance to waterbird habitat, flood control, groundwater recharge, sediment trapping, recreation, natural biological communities, and cultural importance were considered. For remaining terrestrial areas, the presence of rare, threatened, or endangered endemic species, the degree to which

Table 2-1
HERR Criteria for Ranking the Value of Ecosystems Occurrences (Sites)

ECOSYSTEM TYPE	HIGH VALUE CRITERIA (3)	MEDIUM VALUE CRITERIA (2)	LOW VALUE CRITERIA (1)
#1 - Important Off-shore Oceanic areas (2-20 nm)	Highly concentrated offshore pelagic fisheries areas; high densityof humpback whale seasonal populations; biologically productive ocean eddies.	Concentrated offshore pelagic fisheries areas; dense seasonal humpback whale populations; ocean eddies present but with low biological productivity.	Low concentration of commercial fisheries catch; low density of humpback whale populations; ocean eddies absent.
#2 - Important Nearshore Areas (within 2 nm)	Concentrated nearshore commercial fisheries; high coral or shellfish areas; sea turtle feeding areas.	Concentrated nearshore fisheries of recreational value; moderate coral or not known for coral or other marine life.	All other areas within the 2 nm limit.
#3 - Offshore Islets	Islets used by seabirds; native vegetation present; native wildlife present; native invertebrates present.	No native plants/animals, but high recreational value.	Man-made islets with no biological or recreational value.
#4 - Barrier Reef	All (only one example, Kaneohe Bay)	none	none
#5 - Fringing Reefs	Quality reef or coral bottom; high quality marine life present; Ric Guinther resource rank of AA or A; unknown resource surrounded by high quality marine areas.	Degraded or not known for coral coverage or marine life; Ric Guinther resource rank of B.	Virtually destroyed, massive restoration effort required.
#7 - Streams	All HSA "special area" stream systems (any resource category); all HSA stream systems with riparian resource rank of 4pts. or more; HSA stream systems ranked "outstanding" or "substantial" for aquatic, cultural or recreational resources.	Any perennial stream system not ranked "high" by HERR. All HSA ranked "moderate", "without", or "limited" for aquatic resources; HSA stream system with rank of < 4 pts. for riparian resources; HSA stream system with rank of "limited" or "moderate" for recreational or cultural resources.	Intermittent streams that are not part of a "stream system" identified by HSA.
#8 - Estuaries	ESSSP "high quality" rank; DOH "AA"rank; Estuaries associated with stream systems ranked "high" by HERR. (Pearl Harbor West Loch?) Unmodified embayment estuary.	Estuaries associated with stream systems ranked "medium" by HERR. (Pearl Harbor Middle Loch?) Partially modified embayment estuary.	Intermittent estuaries. (Pearl Harbor East Loch?) Heavily degraded embayment estuary.

Table 2-1 (continued)

ECOSYSTEM TYPE	HIGH VALUE CRITERIA	MEDIUM VALUE CRITERIA	LOW VALUE CRITERIA
#9 - Mangrove Swamps	Important for two or more of: aesthetic resources; sediment stabilization; shellfish habitat; finfish habitat; bird habitat; shoreline protection; potential aquaculture site.	Important for one of the categories listed in High criteria.	All others.
#10 - Fishponds	HFS classification of I or IIA (except anchialine pools, which will be categorized separately); other ponds determined high by DHP.	HFS classification of IIB; other ponds determined medium by DHP.	HFS classification of III or IV; or fishponds meeting this criteria.
#11 - Coastlines	ETS nesting or resting areas; Ric Guinther recreation rank of 1 or 2; rare species habitat; all sand beaches; all sloping boulder beaches.	Ric Guinther recreation rank of 3; all other gravel beaches not ranked high.	All other coastlines (not sand, gravel, or sloping boulder beaches; not ETS or rare species habitat).
#12 - Anchialine Pools	HHP database rare species habitat (including birds) or undescribed taxa; pools that are part of a cluster; pools with high water quality or biological integrity.	Structurally modified pools with no native species and degraded water supply. All others not ranked high.	Pools that have been filled during earthmoving or construction.
#13 - Freshwater Lakes and Reservoirs	All natural lakes (because so few exist); artificial lakes with high value for waterbird habitat.	Artificial lakes with high recreational value; fair waterbird habitat value.	Artificial lakes with low recreational value, no waterbird habitat value.
#14 - Hypersaline Lakes	All natural lakes (because so few exist); artificial lakes with high value for waterbird habitat.	Artificial lakes with high recreational value; fair waterbird habitat value.	Artificial lakes with low recreational value, no waterbird habitat value.
#15 - Wetlands	All Elliott & Hall identified wetlands; UHEC identified wetlands, Hawaiian Waterbirds Recovery . Plan identified wetlands; wetlands identified by USFWS as high value.	Wetlands identified by USFWS as medium value.	Wetlands identified by USFWS as low value.

Table 2-1 (continued)

ECOSYSTEM TYPE	HIGH VALUE CRITERIA	MEDIUM VALUE CRITERIA	LOW VALUE CRITERIA
#16 - Coastal Herb and Grasslands	Native Dominated habits over a certain size (to be determined); alien species habitat but containing rare species.	Areas dominated by alien species but having recreational, commercial, esthetic, or cultural value.	Areas dominated by alien species and lacking recreational, commercial, aesthetic, or cultural value.
#17 - Coastal Shrublands #18 - Coastal Forests #19 - Lowland Herb and Grasslands #20 - Lowland Dry Shrublands #21 - Lowland Dry and Mesic Forests #22 - Lowland Wet Forests and Shrublands (to 3000')	Native Dominated habits over a certain size (to be determined); rare species habitat.	Areas dominated by alien species but having recreational, commercial, esthetic, or cultural value.	Areas dominated by alien species and lacking recreational, commercial, aesthetic, or cultural value.
#23 - Montane Dry and Mesic Forests #24 - Montane Wet Shrublands and Forests #25 - Montane Dry and Mesic Shrublands	All USFWS Jacobi mapped areas rated NN or NX; all USFWS Jacobi mapped areas rated XN, with HHP data base rare occurrences. Cloud forests can substantially increase precipitation.	All USFWSS Jacobi mapped areas rated XX and containing HHP data base rare EO's; areas rated XN containing no rare element occurrences; pili grasslands, a'alii shrublands.	All USFWS Jacobi mapped areas rated XX without HHP records of rare element occurrences.

Table 2-1 (continued)

ECOSYSTEM TYPE	HIGH VALUE CRITERIA	MEDIUM VALUE CRITERIA	LOW VALUE CRITERIA
#26 - Subalpine Grasslands and Shrublands	Areas dominated by native species.	Areas dominated by alien species but having recreational, commercial, esthetic, or cultural value.	Areas dominated by alien species and lacking recreational, commercial, aesthetic, or cultural value.
#27 - Subalpine Dry Forests	All	none	none
#28 - Alpine Desert and Shrubland	All	none	none
#29 - Lava Tubes and Caves	Frank Howarth to determine criteria. All tubes or caves associated with any other ecosystem ranked "high" by HERR	Frank Howarth to determine criteria. All tubes or caves associated with any other ecosystem ranked "medium" by HERR	Frank Howarth to determine criteria. All tubes or caves associated with any other ecosystem ranked "low" by HERR.
#30 - Aeolian and Early Successional	All	none	none

the site is a native biological community, and the importance of recreation, cultural, and economic significance were considered. The study of terrestrial site occurrences relied mostly on comprehensive data and analysis compiled by the U.S. Fish and Wildlife Service and The Nature Conservancy. All sites that were existing or proposed for parks, sanctuaries, refuges, reserves, or other forms of protective status were also elevated in importance.

INVENTORY OF ECOSYSTEM SITES

Each occurrence of each ecosystem type was mapped and assigned a site (identification) number. Previous literature formed the basis of the inventory. It became apparent that some of the lowland terrestrial ecosystem types have not been adequately surveyed and could not be fully included in the risk-ranking exercise. The inventory steps included mapping sites (ecosystem occurrences) and recording site information on the data form (see Figure 2-1). It was decided in February 1992 that because of budget constraints the comprehensive inventory and subsequent detailed risk-ranking steps should proceed on an island-by-island basis beginning with Molokai. Molokai was chosen because it is large enough to accomplish a full evaluation, contains examples of most ecosystem types, but is small enough to offer experience and mid-course adjustments before moving on to the other islands.

A special "coarse filter" analysis of about one hundred sites throughout the state, selected on the basis of professional judgement, was also made in the event that funding for comprehensive evaluation of the remaining islands was not received, which unfortunately turned out to be the case.

ECOSYSTEMS STRESSORS LIST

The stressors selected for assessment originate from a variety of human activities that are usually undertaken for direct economic and social benefits. The stressors cause unwanted, perhaps unrecognized, and often unavoidable adverse consequences of the purposeful

Figure 2-1

HAWAII ENVIRONMENTAL RISK RANKING PROJECT: NATURAL ECOSYSTEM OCCURRENCE DATA FORM

A GENERAL INFORMATION

1	WORKSHEET #
2	DATE PREPARED 3-18-92
3	PREPARED BY K. Meier

B OCCURRENCE IDENTIFICATION

4	ECOSYSTEM TYPE Fringing Reef	# 5
5	SOURCE TNCH	
6	SOURCE I.D.# Guinther / Maragos	
7	HERR OCCURRENCE # OA	
8	PLACE NAME Hanauma Bay	
9	ISLAND NAME Oahu	
10	MAP QUAD NAME	# OA

C ECOSYSTEM OCCURRENCE VALUES

		V	U
11	BIODIVERSITY	3	1
12	RECREATION	3	1
13	CULTURAL/AESTHETIC	3	1
14	ECONOM/PRODUCT/~~RESEARCH~~	3	1
15	TOTAL ECO-SCORE (SUM)	12	
16	OVERALL UNCERTAINTY		

D REMARKS

3=HIGH 2=MEDIUM 1=LOW V=VALUE U=UNCERTAINTY LEVEL

E STRESSOR RANKING MATRIX

SEVERITY X FREQUENCY = RISK SCORE

44 UNCERTAINTY	POSSIBLE STRESSORS ON THE ECOSYSTEM OCCURRENCE	30 IRREVERSIBLE LOSS OF UNIQUE RESOURCE	31 TOTAL LOSS WITH LONG RECOVERY	32 MAJORITY LOSS WITH LONG RECOVERY	33 PARTIAL LOSS WITH LONG RECOVERY	34 PARTIAL LOSS WITH RAPID RECOVERY	35 MINOR LOSS WITH RAPID RECOVERY	36	37 PROGRESSIVE, INCREASING	38 ONGOING, CONTINUAL	39 OCCASIONAL	40 LIKELY IN NEAR FUTURE	41 PLAUSIBLE	42 REMOTELY POSSIBLE	43 PRODUCT (SEVERITY X FREQUENCY)
	17 ALIEN SPECIES	6	5	4	3	2	1	.	6	5	4	3	2	1	
2	18 TOXIC CHEMICALS	6	5	4	3	2	1	.	6	5	4	3	2	1	6
1	19 NUTRIENTS/BIO OXYGEN DEMAND	6	5	4	3	2	1	.	6	5	4	3	2	1	20
	20 EARTHMOVING/DEVELOPMENT	6	5	4	3	2	1	.	6	5	4	3	2	1	
2	21 EROSION/SEDIMENTATION	6	5	4	3	2	1	.	6	5	4	3	2	1	8
	22 WATER DIVERS/CHANNELIZATION	6	5	4	3	2	1	.	6	5	4	3	2	1	
	23 NOISE OR LIGHT	6	5	4	3	2	1	.	6	5	4	3	2	1	
	24 HEAT/THERMAL	6	5	4	3	2	1	.	6	5	4	3	2	1	
1	25 HUMAN CROWDING	6	5	4	3	2	1	.	6	5	4	3	2	1	24
	26 GLOBAL CHANGE	6	5	4	3	2	1	.	6	5	4	3	2	1	
	27 FIRE	6	5	4	3	2	1	.	6	5	4	3	2	1	
	28 EXPLOSIVES	6	5	4	3	2	1	.	6	5	4	3	2	1	
46	29 **TOTALS**														52 (45)

F SUMMARY

47	OVERALL UNCERTAIN SCORE	1
48	TOTAL ECO-SCORE	12
49	TOTAL RISK SCORE	52
50	PRIOITY SCORE	624

G REFERENCES AND NOTES:

activities (Table 2-2). The table is useful in the reverse direction as well; i.e., when a stressor impact is ranked high (in likelihood of occurrence and magnitude of damage), then the reduction of that risk will depend on changes in management of the activities that originated the stressor. For example, sediment is a high risk to coral reefs, bottom ecosystems, and fisheries. Sediment arises from erosion in construction, agriculture, and uncontrolled disturbance of vegetation and soil by feral animals. Reducing risk from sediment requires revised management of all these causal activities.

The final list of 12 stressors includes categories that have not usually been emphasized in previous ecological risk assessments elsewhere: alien species, light and noise, explosives, etc. Damage from alien species has historically been of particular concern in Hawaii because of the high degree of endemism and vulnerability of native species and ecosystems. Due to reasons discussed later, global climate change, although included as a HERR stressor, was not thoroughly evaluated because of its scale, which is inconsistent with the other stressors. Eliminating the causes of climate change as a stressor is a global challenge, while reducing the <u>effects</u> of climate change here is important for Hawaii's ecosystems.

Eight of the stressors are related to the HERR study's original list of Hawaii's Environmental Problem Areas, shown in Table 1 of the Executive Summary, in order to facilitate comparative ranking of the risks using both human health and ecosystems integrity. Toxic chemicals are the major stressors common to both human health and ecosystems. The risk to ecosystems from toxic chemicals adds to the priority for management attention to pesticides, industrial wastewater discharges, and especially nonpoint sources of water pollution (i.e., sediment and nutrients). These nonpoint source stressors are a hazard to economic welfare in Hawaii through damages to water contact recreational activities and to quality of life because of esthetic degradation.

Table 2-2

Human Activities as Origins of Ecosystems Stressors

Stressors Impacting Sites	Parks/preserves	Forestry	Aquaculture/mariculture	Agriculture/grazing	Tourism/recreation (e.g., hunting, golf courses)	Military installations and activities	Construction	Energy production (geothermal)	Transportation (roads, airports, harbors)	Industry and commerce	Urbanization	Consumption of goods and services	Population growth	
1) Alien species			→	→	→	→	→		→		→			Established plants or animals introduced to the islands that were not here before. Some escape domestication or cultivation to become feral.
2) Toxic chemicals				→		→				→		→	→	Pesticides, heavy metals, solvents, acids, oil, and grease.
3) Nutrients/BOD			→	→	→	→				→		→	→	Plant nutrients including carbon, nitrogen, and phosphorous. Biological oxygen demand for decomposing organic materials.
4) Earth moving/development	→	→		→	→	→	→		→	→	→			Activities involving the clearing of vegetation, removal of soil, or changes in runoff patterns.
5) Erosion/sedimentation	→	→		→	→		→		→		→			Soil disturbance and displacement by wind or rain. Sediment delivery.
6) Water diversion		→	→	→	→	→		→		→		→	→	Water resources development, channelization, dams and reservoirs, wells.
7) Noise/light					→	→	→	→	→	→	→		→	Unnatural intensity, timing or place of occurrence.
8) Heat								→		→	→	→		Heated water discharges or other change in temperature of an ecosystem.
9) Human crowding	→				→						→		→	Trampling of plants, soil compaction, litter, disruption, turbidity, crowded beaches and parks, overfishing.
10) Global climate change		→		→				→		→		→		Warming and consequent changes in rainfall patterns, sea level and storms rise. Ozone depletion leading to increased UV-B.
11) Fire		→		→	→	→		→	→					Unnatural occurrence of fire in vegetation due to human activity, accidental or purposeful.
12) Explosives						→	→		→					Civilian construction or military activities.

Human Activities

ECOLOGICAL ENDPOINTS

When determining ecological worth, there is no single set of values to protect or restore, as contrasted with human health risk assessment, where the only "endpoints" are effects on human beings. There are many ecological endpoints that we as a society care about, such as a reduction in fisheries, loss of biodiversity, erosion of beaches, etc. Different ecosystem types have different endpoints to consider when assessing stressor damage. The HERR methodology utilizes a qualitative assessment of stressor effects on _all_ ecosystem values; those with a social relevance as well as those with a biological relevance. For example, the loss of a sandy beach may have a greater social impact (on the economy or quality of life) than biological impact. All four components of ecosystem occurrence value (biological, cultural/esthetic, recreational and economic) are considered when evaluating stressor effects.

DATA ANALYSIS

Data from the Molokai Island forms were compiled into a database management system developed for the ecological portion of the HERR project. Initial testing and analysis of the database were conducted for the island of Molokai. Experience gained from the Molokai computation will lead to further refinement of data compilation, subsequent computer entry, and analytical procedures for the remaining full-island evaluations, if funded. A number of calculations were greatly facilitated by relying on the computer-based system: assessing the relative importance of each stressor, assessing the relative degree of stress to each ecosystem type, estimating the relative importance of the site occurrences of each ecosystem type, assessing which stressors caused the most risks to the most ecosystem types and occurrences, identification of specific sites of priority attention based upon the risk assessment exercise, etc.

MAPPING

Mapping is an integral part of the risk-ranking exercise. Physical location, site boundaries, and size are important considerations in determining both value and risk. Valuable ecosystem occurrences were drawn on overlays at a fairly large scale, 1:50,000 (except the big island of Hawaii, which was mapped at 1:100,000). Up to date, easily available, detailed USGS maps were used as base maps. Map "layers" were prepared to illustrate geographic attributes such as native vegetation, rare or endangered species habitat, regions of historic/cultural significance, etc. Additional overlays show physical stressors such as development plans, feral animal distribution, sewage discharge points, alien plant infestations, etc. Some mapped attributes are perceived as both a stressor and value: public trails, campgrounds and parks, and concentrated fisheries areas.

When the "layers" are viewed concurrently, a good picture of an area's assets and stresses are visible, and proximity to other valuable areas or potential sources of stress is made clear. Reference by the expert panel to mapped sites throughout the ranking exercise assured that the proper site was being considered.

As Molokai has a fairly small land area, and only 250 ranked sites, it was possible to complete the mapping exercise using hand-drawn maps. However, in order to compile and manipulate the enormous amount of data generated for the other main islands, we utilized a windows-driven desktop geographic information system (GIS) designed specifically for risk ranking. The software merges our current database with a GIS mapping facility to allow visual and geographic analysis of HERR occurrence information. By using a GIS system, manipulation of geographic data will be faster and more reliable, intuitive trends more easily spotted, and production facilitated of shaded thematic maps for presentation.

THE 20 MARCH 1992 WORKSHOP
INVOLVING THE RANKING OF ONE HUNDRED SITES

Constant dialogue was maintained with contributing scientists during the ecological risk-ranking exercise to ensure that procedures and criteria were reasonable and defensible. The December 1991 workshop was particularly valuable for feedback during the development of the procedures for the study. Another workshop was also held in late March 1992 after completing the risk-ranking exercise for the first island (Molokai). This workshop accomplished two purposes: (1) to review the Molokai exercise to improve the process for the remaining inhabited islands; and (2) to identify and rank about one hundred representative high-value sites on the remaining islands. The latter was necessary in the event that funds were inadequate to complete the full risk-ranking exercises for the remaining main islands. These one hundred additional sites were selected as being among the most important in the state, representing good examples of each ecosystem type, and also being at potential risk from one or more important stressors. The workshop allowed environmental professionals from several agencies and organizations to participate in the ranking, analytical, and computational exercises for the one hundred sites.

The experts were instructed to select sites with apparent high value that, in their judgement, were now or imminently under stress, so that the priority score would also likely be high. The resulting set of one hundred sites is thus an immediately useful advisory to the state government. When the exhaustive and comprehensive ranking of all ecosystem sites (perhaps two thousand) is completed, many of these sites will quite probably be in the <u>higher</u> priority component of the total. It is also useful to note that some of the high-value sites turned out to be at <u>lower</u> risk because of current protective management or lack of access or development activity.

The island of Molokai has been completely assessed, and the highest priority sites there were added to the workshop set.

It is important to consider that the limited ranking of these sites, although conducted with the best professional judgement available, is not as accurate as the comprehensive Molokai methodology for several reasons. Due to time constraints, many of the sites were necessarily large and boundaries uncertain. Risks to smaller sites can be predicted more accurately. For example, the severity of damage from a fire can be much more easily estimated for a 5-acre shrubland than for a 500-acre area. Values, too, are more difficult to ascertain in large areas, because of the complexity of Hawaii's many ecosystems and the varied effects of human interaction with these ecosystems. For example, by studying vegetation, rare species distribution, and recreational maps, we can predict with fair accuracy the attributes of a specific small site. However, when considering an entire subalpine shrubland of hundreds of acres with uncertain boundaries, pockets of extremely valuable or extremely "worthless" areas can be overlooked.

Figure 2-1 shows the data sheet for Hanauma Bay and illustrates the method. Instructions given to the experts are reproduced as follows:

Estimating Risks to Ecosystem Sites and General Instructions for Completing Risk Ranking at Specific Sites

Risk is described as the product of the frequency of occurrence and the severity of some adverse impact. Only a semi-quantitative estimation is possible with the present understanding of ecosystems and their response to stress. Nevertheless, technical professional judgement can be applied in an orderly way to yield valid comparison and relative ranking of risks.

For a given stressor at a specific valuable occurrence (or site), the severity is rated on a scale of 1-6 on the basis of percent of the resource that is lost or damaged, and the time required for recovery. The scalar is defined as follows:

6 - Irreversible loss of a unique resource or extinction of a species
5 - Total loss of a resource with recovery possible only over many decades
4 - More than 50% loss of resource with long-term recovery possible
3 - 10-50% loss of resource with long-term recovery possible
2 - 10-50% loss of resource and short-term recovery expected
1 - Less than 10% loss of resource with rapid recovery expected

The frequency of impact occurrence is rated on the following scalar:

6 - Progressive, increasing frequency
5 - Ongoing, continual
4 - Occasional
3 - Likely in near future
2 - Plausible
1 - Remotely possible

The frequency and severity ratings are multiplied to give a risk estimate of 1 to 36. The risk from each significant stressor is estimated separately and the ratings of the three highest-scored stressors are added to find the Total Risk Score.

Risks were estimated using the Natural Ecosystem Occurrence Data Form developed by the Hawaii Environmental Risk Ranking Project. The Data Form is divided into 7 parts, and is to be filled out for each occurrence (site) of an ecosystem type.

General Instructions for Filling Out the Data Form

A. General Information
The first 3 entries identify the worksheet number, date of preparation, and persons completing the form.

B. Occurrence Identification
This box includes name and number of the ecosystem type (line 1), and source documents used (line 2). If this occurrence has an I.D.# in the source document, enter on line 3. A HERR occurrence number will be assigned on line 4. (HERR codes are assigned according to: island#-quad#-10-10 grid #, i.e., 02-05-E4). Enter site place name on line 5, island name on line 6, and quad name and number on line 7.

C. Ecosystem Occurrence Values
Use entries 11-16 to assign occurrence value and uncertainty level (3=high, 2=medium, and 1=low). Assign a value to <u>each</u> of the four components of ecosystem worth: Biodiversity/Biological Resources, Recreational, Cultural/Aesthetic, and Economic/Productivity (lines 11-14). Use the Uncertainty (U) column to rate the uncertainty level of information used to value each component. If insufficient data are available to rank one of the values, enter a default value of 1, with a high uncertainty value of 3. Overall Eco-score (line 15) is the sum of all four values. If Overall Ecovalue is less than 6, do not continue with the form. Overall Uncertainty (line 16) is the sum of all four uncertainty values.

D. Remarks

This area is used to explain uncertainty scores, or the basis for "best professional judgement" when used to assign values, if source data are meager or old. Other remarks about resources, assets, special characteristics or uncertainties should also be added.

E. Stressor Ranking Matrix

The left side of the matrix lists 12 potential stressors (lines 17-28) to this ecosystem occurrence. Each applicable stressor should be evaluated for both severity and frequency of impact. There are 6 levels for Severity (entries 30-35), and 6 levels for Frequency (entries 37-42). Circle one severity value and one frequency value for each applicable stressor. If uncertain about frequency or severity of a stressor, circle a value using best professional judgement, and enter an Uncertainly Level of 1, 2, or 3 (low, medium, or high) in the left column (entry 44), opposite that stressor.

Risk Score (entry 43) is the product of Severity times Frequency of each stressor. The three highest Risk Scores in the far right column (entry 43), are added together, and this sum entered in Totals (entry 45), and Total Risk Score (line 49) of the Summary Box.

Total Risk Score (entry 43) cannot exceed the equivalent of 3 stressors, collectively exerting maximum risk on an ecosystem occurrence, 6X6X3=108. This cap is placed on Risk Scores to avoid skewing the importance of the stressors relative to the value of the Ecosystem Occurrence Values when calculating priorities in the final step.

F. Summary

Overall Uncertainty Score (line 47) is the sum levels of uncertainty upon which the ratings have been based.

The final entry in the Summary Box is the Priority Score (entry 50). This is the product of the Total Eco-score (48) and the Total Risk Score (49).

G. References and Notes

This section lists sources of data (author, date, title, publisher) or personal references upon which evaluation has been based, including unpublished, verbal, aerial photographic, and map sources.

UNCERTAINTY

The scoring of values and stressors is apparently fairly reproducible when the site has been studied and visited recently (i.e., when the uncertainty was low). The variation among different experts in choosing levels of scalars for stressor severity and likelihood was usually only 1 level (e.g., 3 or 4, 5 or 6). The variation among experts in assigning value levels was also about 1. Thus, a value score might typically vary from 9 to 10, and a stressor risk score (top three) might vary from 30 to 40, yielding a range of the final priority score of 270-400, with an expected value of 335. Assuming a mid-range of 10x30 = 300 to 9x40 = 360, the method has an inherent error of about ± 10% of the priority score. If uncertainty is high (due to lack of observations or understanding), then the error is larger, perhaps ± 25% of the priority score, and the score is more likely to change when more information is obtained. The priority scores were distributed over a range of 100-700, so that discrimination of higher priority sites is possible even with a ± 25% error and is quite good with a ± 10% error.

FINDINGS: ONE HUNDRED SITES ANALYSIS (TABLES 2-3 to 2-8)

Analysis of the data sheets for the one hundred sites selected by the expert panel yields the following general findings:

1. The greatest number of valuable ecosystem sites are in the coastal area, including wetlands, fishponds, coastlines, and fringing reefs. These sites are heavily stressed by alien species, sedimentation, plant nutrients, and human crowding.

2. Runoff of rainfall on the landscape through agricultural lands, urban areas, and disturbed surfaces of natural areas carries sediment, toxic chemicals, and nutrients into streams, wetlands, fishponds, and coastal waters. This "nonpoint source" pollution is a substantial risk to the values and uses of aquatic ecosystems.

Tables 2-3 to 2-8: Island-by-island summaries of the HERR one hundred ecosystem site analyses: (Table 2-3 - Hawaii; Table 2-4 - Kauai-Niihau; Table 2-5 - Lanai; Table 2-6 - Maui-Kahoolawe; Table 2-7 - Oahu; and Table 2-8 - Molokai). Except for Molokai, these tables

Stressor abbreviations for Tables 2-3 to 2-8

Al	: Alien Species
Crowd	: Human Crowding
EMD	: Earth Moving/Development
Eros	: Erosion/Sedimentation
Ex	: Explosives
Fire	: Fire
GC	: Global Change
HT	: Heat/Thermal
NL	: Noise or Light
Nut	: Nutrients/Bio Oxygen Demand
Tox	: Toxic Chemicals
WDC	: Water Diversion/Channelization

U - means uncertainties exist in information for value and/or stress estimates

C - means relative certainty concerning the information

provide the place names, ecosystem types, risk score, priority score, uncertainty score, and the three most important stressors for each site examined for each island. The Molokai data include the highest-ranked sites from the full-island analysis described in the next section.

Tables 2-3 to 2-8 summarize the sites selected by the expert panel, grouped by island. Molokai Island data were derived from the full-island analysis described in the next section. Those sites with a priority score of 300 and above are shown in boldfaced type and are judged to be higher in priority for management attention. The three greatest stressors are listed for each site and inspection confirms the importance of alien species, erosion-sedimentation, and human crowding in affecting these selected high-value sites (see Table 2-9). Earthmoving development and water diversion activities are also major stressors to low-elevation and aquatic ecosystems, while fire is a risk to valuable terrestrial sites at higher elevations. Coastal grass and shrublands are extremely vulnerable to fire because of high recreational use.

Even where the values of ecosystem sites are well established, there may be considerable uncertainty about the severity and frequency of occurrence of stressors.

Table 2-3

ISLAND OF HAWAII

Site	Ecosystem Type #	Ecosystem Type Description	Ecosyst Value Score	Three greatest Stressors	Risk Score	Priority Score	Uncer-tainty
Loihi Seamount	1	Offshore Oceanic	6	HT	8	48	U
Lapakahi	2	Nearshore	10	Nut, Eros, Crowd	20	200	U
Coconut Island	**3**	**Offshore Islets**	**10**	**Nut, NL, Crowd**	**32**	**320**	**U**
Moku Auea (Goat Island)	**3**	,,	**10**	**AI, NL, Crowd**	**34**	**340**	**C**
Honaunau	5	Fringing Reefs	11	Nut, NL, Crowd	20	220	U
Puako	5	,,	10	Nut, NL, Crowd	27	270	U
Kealakekua	5	,,	11	Tox, Nut, Crowd	27	297	U
Hamakua Streams	**7**	**Streams**	**9**	**AI, EMD, WDC**	**37**	**333**	**C**
Loko Aka Pond	10	Fishponds	9	AI, Crowd	15	135	C
Keaau (Shipman)	10	,,	7	AI, Crowd	20	140	C
Lahuipuaa (Maunalani)	10	,,	10	AI, Tox, Nut	18	180	C
Kaloko	10	,,	10	AI, EMD, Crowd	21	210	U
Punaluu	11	Coastlines	9	EMD, Eros, Crowd	13	117	U
Kahaluu	11	,,	10	Nut, EMD, Crowd	27	270	U
Ka Lae	**12**	**Anchialine Pools**	**10**	**AI, Nut, Eros**	**39**	**390**	**C**
Opae Ela - Makalawena	15	Wetlands	8	AI, EMD, Crowd	20	160	C
Wailoa	**15**	,,	**11**	**AI, Tox, Crowd**	**35**	**385**	**C**
Puuwaa	21	Low Dry/Mesic Forests	9	AI, EMD, Fire	31	279	C
Honokane Low Wet	22	Low Wet Forests	9	AI, Eros, WDC	27	243	C
Windward Hamakua Forest	**22**	,,	**12**	**AI, Eros, WDC**	**29**	**348**	**C**
Kapapala Kau FR	**23**	**Montane Dry/Mesic Forests**	**10**	**AI, Eros, WDC**	**33**	**330**	**C**
Hualalai	**25**	**Montane Dry/Mesic Shrub**	**11**	**AI, EMD, Fire**	**42**	**462**	**C**
Mauna Kea - Mauna Loa	**26**	**Sub-alpine Grass/Shrub**	**10**	**AI, EMD, Fire**	**39**	**390**	**C**
Mauna Kea	27	Sub-alpine Dry Forests	9	AI, Eros, GC	28	252	C
Mauna Loa	28	Alpine Desert	6	AI	4	24	C
Mauna Kea	28	,,	11	EMD, Eros, Crowd	21	231	C
Kilauea East Rift	30	Aeolian	6				C

Table 2-4

ISLAND OF KAUAI

Site	Ecosystem Type #	Ecosystem Type Description	Ecosyst Value Score	Three greatest Stressors	Risk Score	Priority Score	Uncer-tainty
Mana "Cut" or "Crack" (Reef)	2	Nearshore	9	Nut, Crowd, Ex	8	72	U
Na Pali	2	"	10	Eros, NL, Crowd	15	150	C
Poipu	2	"	10	Nut, Eros, NL	26	260	C
Mokuaeae Island	3	Offshore Islets	8	Eros, NL, Crowd	7	56	U
Nualolo Kai	5	Fringing Reefs	11	Tox, Eros, Crowd	20	220	U
Haena	5	"	11	Nut, Eros, Crowd	27	297	C
Hanalei	**7**	**Streams**	**11**	**Al, Eros, WDC**	**40**	**440**	**C**
Menehune (Alekoko)	**10**	**Fishponds**	**9**	**Al, Eros, WDC**	**34**	**306**	**C**
Polihale (Barking Sands)	11	Coastlines	10	Tox, Nut, Eros	16	160	U
Hanalei Bar (Beach)	11	"	9	Nut, Eros, Crowd	27	243	U
Waita Reservoir	13	Freshwater Lakes	9	Al, Tox, Eros	29	261	C
Mana	**15**	**Wetlands**	**6**	**Al, Eros, WDC**	**55**	**330**	**C**
Hanalei	**15**	**"**	**10**	**Al, EMD, Eros**	**39**	**390**	**C**
Polihale	17	Coastal Shrublands	10	Al, Crowd	27	270	C
Kokee/Pule Kapele	20	Low Dry Shrubland	7	Al, Eros, Fire	42	294	C
Waimea/Olukele Canyon	**21**	**Low Dry/Mesic Forests**	**9**	**Al, Eros, Fire**	**42**	**378**	**C**
Alakai Bogs	24	Montane Wet Shrub	11	Al, WDC, NL	23	253	C
Koloa Cave	29	Lava Tubes	6	Al, EMD, Crowd	28	168	C
Lehua Island (Niihau)	3		7	Al, EMD, Crowd	35	245	C

Table 2-5

ISLAND OF LANAI

Site	Ecosystem Type #	Ecosystem Type Description	Ecosyst Value Score	Three greatest Stressors	Risk Score	Priority Score	Uncer-tainty
Kaumalapau Harbor	2	Nearshore	9	Tox, Eros, Crowd	20	180	U
Puu Pehe	3	Offshore Islets	8	AI	9	72	C
Manele - Hulapoe	**5**	**Fringing Reefs**	**12**	**Tox, Eros, Crowd**	**27**	**324**	U
Shipwreck Beach	**11**	**Coastlines**	**11**	**EMD, Eros, Crowd**	**28**	**308**	C
Kanepuu	**21**	**Low Dry/Mesic Forests**	**7**	**AI, Eros, Fire**	**43**	**301**	C
Lanaihale	**24**	**Montane Wet Shrub**	**11**	**AI, Eros, Crowd**	**37**	**407**	C

Table 2-6

ISLAND OF MAUI

Site	Ecosystem Type #	Ecosystem Type Description	Ecosyst Value Score	Three greatest Stressors	Risk Score	Priority Score	Uncer-tainty
Auau Channel	**1**	**Offshore Oceanic**	**12**	**Eros, NL, Crowd**	**33**	**396**	C
Ma'alaea Bay	**2**	**Nearshore**	**12**	**Nut, Eros, NL**	**35**	**420**	C
Molokini Reef	**5**	**Fringing Reefs**	**12**	**Tox, NL, Crowd**	**31**	**372**	C
Honolua Bay	**5**	"	**11**	**Tox, Eros, Crowd**	**31**	**341**	U
Puu Olai - North	**5**	"	**12**	**Nut, Eros, Crowd**	**29**	**348**	U
Makamakaole Stream	**7**	**Streams**	**8**	**AI, Eros, WDC**	**42**	**336**	C
Hanawi	**7**	"	**8**	**AI, Eros, WDC**	**45**	**360**	C
Ma'alaea	**11**	**Coastlines**	**10**	**Nut, Eros, Crowd**	**36**	**360**	U
Ahihikinau	12	Anchialine Pools	9	AI, Crowd	16	144	C
Kealia Pond/Maalae Mudflats	**15**	**Wetlands**	**8**	**AI, Tox, Eros**	**38**	**304**	C
Waihee, Waiehu	**15**	"	**8**	**AI, EMD, Eros**	**39**	**312**	C
West Maui Pili Grass	**19**	**Lowland Herb**	**9**	**AI, Eros, Fire**	**39**	**351**	C
West Maui	**20**	**Low Dry Shrubland**	**9**	**AI, Eros, Fire**	**39**	**351**	C
Puu O Kali	21	Low Dry/Mesic Forests	6	AI, EMD, Fire	27	162	C
West Maui - Puu Kukui	24	Montane Wet Shrub	10	AI	15	150	C
Haleakala	**24**	"	**11**	**AI, Eros, WDC**	**45**	**495**	C
Haleakala	27	Sub-alpine Dry Forests	11	AI, Crowd	16	176	C
Puu Mahoe	29	Lava Tubes	8	AI, Tox, EMD	27	216	C
Kahoolawe - East	2	Nearshore	10	Eros, Ex	21	210	U
West Kahoolawe Cotton Shrub	17	Coastal Shrublands	6	AI, Eros, Fire	38	228	C

Table 2-7

ISLAND OF OAHU

Site	Ecosystem Type #	Ecosystem Type Description	Ecosyst Value Score	Three greatest Stressors	Risk Score	Priority Score	Uncer-tainty
Penguin Banks	1	Offshore Oceanic	10	Tox, Crowd	13	130	U
Kaneohe Bay Reef	**4**	**Barrier Reef**	**12**	**AI, Nut, Crowd**	**48**	**576**	C
Hanauma Bay	**5**	**Fringing Reef**	**12**	**Crowd, Eros, Nut**	**52**	**624**	C
Kahana	**7**	**Streams**	**11**	**AI, Eros,WDC**	**48**	**528**	C
Kahana	**8**	**Estuaries**	**12**	**AI, Eros, WDC**	**31**	**372**	C
Heeia Kea	9	Mangrove Swamps	9	Tox, EMD, Eros	14	126	U
Nuupia West of Mokapu Blvd	**10**	**Fishponds**	**11**	**AI, Tox, Eros**	**38**	**418**	C
Kahuku (East Side)	11	Coastlines	11	Nut, NL, Crowd	20	220	C
Kahuku (West)	**11**	"	**11**	**EMD, NL, Crowd**	**39**	**429**	C
Nuupia East of Mokapu Blvd	14	Hypersaline Lakes	6	AI, Eros, WDC	25	150	U
Ukoa Marsh, Haleiwa	15	Wetlands	7	AI, EMD, WDC	37	259	C
Kahuku	**15**	"	**8**	**AI, EMD, Eros**	**39**	**312**	C
Kahuku	**16**	**Coastal Herb**	**9**	**AI, Eros, Crowd**	**35**	**315**	C
Kahuku	**17**	**Coastal Shrublands**	**9**	**AI, Eros, Crowd**	**35**	**315**	C
Kaena Pt	**17**	"	**10**	**AI, Eros, Crowd**	**42**	**420**	C
Waianae Mountains	**21**	**Low Dry/Mesic Forests**	**9**	**AI, Eros, Fire**	**47**	**423**	C
S. Waianae Summit	**22**	**Low Wet Forests**	**7**	**AI, Eros, Fire**	**44**	**308**	C
Koolau Summit	**22**	"	**11**	**AI, Eros, Crowd**	**32**	**352**	C
Kaala	24	Montane Wet Shrub	8	AI	15	120	C
Pupukea Psuedo Scorpion Cave	29	Lava Tubes	7	AI, EMD, Crowd	35	245	C

Table 2-8

ISLAND OF MOLOKAI

Site	Ecosystem Type #	Ecosystem Type Description	Ecosyst Value Score	Three greatest Stressors	Risk Score	Priority Score	Uncer-tainty
Kapukalaulua to Kamahuehue Fishpond	5	Fringing Reefs	11	Nut, EMD, Eros	47	517	U
Kipapa to Kaopeahina Fishpond	5	"	11	EMD, Eros, Crowd	54	594	C
Halawa	7	Streams	12	Al, Eros, WDC	34	408	C
Kawela	7	"	10	Al, Eros, WDC	44	440	U
Halawa Bay	8	Estuaries	11	Al, Eros, Crowd	54	594	U
Kipapa	10	Fishponds	8	Al, EMD, Eros	65	520	C
Ooia Pond to Kaunakakai	11	Coastlines	9	Al, EMD, Crowd	62	558	U
Kipapa to Kaopeahina Fishpond	11	"	11	Al, EMD, Eros	53	583	U
Kaunakakai to Kapukalaulua	11	"	12	Al, EMD, Eros	50	600	U
Oalapue Fishpond	15	Wetlands	10	Al, EMD, Eros	70	700	C
South Molokai Mud Flats	15	"	8	Al, EMD, Eros	96	768	C
Ilio Pt to Puu Koai	16	Coastal Herb	11	Al, EMD, Eros	42	462	U
Ka Le Mau to Makalii	16	"	11	Al, Crowd, Fire	43	473	C
Moomomi Preserve	17	Coastal Shrublands	12	Al, Eros, Crowd	42	504	C
Hakaaano	18	Coastal Forests	10	Al, Eros, Fire	56	560	C
Kikipua Point	18	"	10	Al, Eros, Fire	56	560	C
Kamiloloa	20	Lowland Dry Shrubland	7	Al, EMD, Fire	66	462	U
Wailau Trail, East to Kainalu Gulch	21	Low Dry/Mesic Forests	8	Al, EMD, Eros	63	504	U
Puu Ohelo Cliffs & Valley	22	Low Wet Forests	10	Al, Tox, Eros	50	500	U
Kalaupapa Caves	29	Lava Tubes	12	Al, EMD, Crowd	60	720	C

Table 2-9

Relative Importance of Stressors in the 100-Site Statewide Survey

Stressor	Sites Where This Stressor Is Considered To Be in the Top Three (%)
Alien species	70
Erosion/sedimentation	63
Human crowding	45
Earthmoving/development	30
Toxic chemicals	15
Water diversion/channelization	15
Nutrients/bio oxygen demand	15
Fire	14
Noise/light	13
Explosives	< 2
Global warming	< 2
Heat/thermal	< 2

Based on the one hundred site analysis, severe loss of valuable resources and unique sites was judged to be occurring or imminent on the following island sites:

Hawaii

- stream (Hamakua)
- upland mesic shrublands (Hualalai, Mauna Kea)

Kauai

- stream (Hanalei)
- wetland (Mana)
- low-elevation dry shrubland/forests (Waimea, Kokee)

Maui

- upland forests and shrublands on Lanai
- streams (Hanawi, Makamakaole)
- coastline (Maalaea)
- wetlands (Kealia, Waihee)
- lowland and one upland (west Maui)
- montane shrubland (Haleakala)

Oahu

- barrier reef (Kaneohe)
- fringing reef (Hanauma)

- stream (Kahana)
- fishpond complex (Nuupia)
- coastline (west Kahuku)
- wetlands (Ukoa, Kahuku)
- coastal herb/shrublands (Kahuku, Kaena)
- lowland forests (Waianae)
- cave (Pupukea)

Molokai

- examples of virtually all ecosystem categories evaluated for Molokai during the full-island analysis (see Table 2-12).

As noted earlier, lowland and coastal terrestrial habitats, wetlands, streams, and some coral reefs appear more stressed than upland ecosystems. Maui and Oahu islands had the greatest proportion of sites at severe risk, compared to the other islands included in the one hundred site analysis (excluding Molokai). This is not surprising since the density of the human population is higher on these two islands.

Crowding/overfishing, soil erosion and sedimentation, and nutrients/biochemical oxygen demand were listed as the three most important stressors affecting marine ecosystems. In contrast, alien species, soil erosion/sedimentation, fire, and earthmoving/development were indicated as the most important stressors for terrestrial ecosystems. For freshwater ecosystems, alien species, earthmoving/development, human crowding/encroachment, water diversion, and soil erosion and sedimentation were all frequently listed as the top stressors.

UNCERTAINTY

Uncertainty was not a major factor in affecting the risk ranking for the areas covered in the one hundred site analysis. All Kauai and Oahu sites with high uncertainty values scored low in terms of risk and priority scores. All but one site on the island of Hawaii (Coconut Island) combined high uncertainty with low priority scores. Only one Lanai site (Manele-Hulapoe fringing reef) scored high in both uncertainty and priority. All three sites on Maui scoring high in uncertainty (Honolua Bay, Puu Olai, Maalaea) also showed high priority scores.

Molokai, in contrast, was evaluated at a very high level of resolution, with many of the sites as small as one acre. Uncertainty scores were high in approximately half of the rated occurrences. Although the raters were familiar with the assets and threats to the specific areas, in many cases they were uncertain about the values or boundaries of a specific spot on the map. Uncertainty scores can frequently be higher when describing a specific area in great detail, as opposed to a large generalized region described loosely. Because of the coarse filter approach used in the "100 site" workshop, standards for describing value were not as strict as those applied in the Molokai study.

Despite the intent of the 100 site workshop panel to focus on valuable sites thought to be at high risk, many (35%) were determined not to be at high risk.

SPECIFIC SITES

Examination of specific sites illustrates the risks to ecosystems in Hawaii.

Hanalei, Kauai, comprises a stream, coastline, estuary, and wetlands that have exceptional value in all four categories. Alien species of plants and animals are an ongoing stress on biodiversity and economic productivity, causing damage to the stream and wetlands that can only be repaired over a long time. The estuary is under stress from overcrowding and nutrients. Sedimentation and development activities that involve earthmoving and water diversion also impact the area. These factors combine to give Hanalei a higher priority rank for attention.

Kahana estuary and stream on Oahu drain only light agricultural activities in the watershed but are at risk from sediment, water diversion, and alien species. The estuary is classified as a water quality limited segment (see Part 1) because of this nonpoint source pollution. The natural soil erosion rate is exacerbated by feral pigs.

Halawa stream, wetlands, and bay on east Molokai form a highly valuable site that is currently being increasingly damaged due to sediment delivered from upland erosion caused by feral animals. Alien plant species and human overcrowding also are causing partial value loses that will require a long time for recovery.

Mauna Kea on Hawaii has alpine and subalpine desert sites with high biodiversity and cultural/esthetic values that are under continual stress from alien species; these sites occasionally suffer partial loss of values from road building and recreational impacts.

The **Maalaea** coast and nearshore area of Maui are high-value sites threatened by sediment. Nutrients are also a stressor, causing excessive growth of algae and seaweed that interferes with recreational swimming, snorkeling, and diving. The nutrients' likely source is from treated sewage that is pumped into disposal wells and then flows laterally into the ocean. Adverse impacts to humpback whale populations are threatened by growth in tourism and related activities.

On Hawaii, the fringing reef along **Kealakekua** and **Honaunau** supports high values of biodiversity, recreation, and cultural sites. There is some uncertainty about the stress on this reef, and more monitoring is needed to clarify the apparently high risk from nutrients and sediment coming off the landscape.

Kaneohe Bay is the most-studied high-value site in the state and has the only barrier reef in Hawaii. Despite partial recovery of the bay following relocation of the sewage outfall in 1978, this ecosystem is still at high risk from nutrients, toxic chemicals, and sediment that wash off the intensely developed watersheds behind the bay. Bottom algae (some alien species) in its lagoon are again increasing and may again threaten some coral populations.

Hanauma Bay is the best-known recreational site in Hawaii. Crowding is recognized as the major stressor, and some controls have been applied (e.g., closing the park on Wednesday mornings, restricted parking, and banning busing of tourists). Feeding of fish by visitors has altered the natural composition of the fish community. The corals are heavily damaged from being walked on. There is some evidence that nutrients are enriching the water and adversely affecting corals. Severe damage to this extremely valuable site is ongoing, and it is ranked as one of the highest priorities for further management attention.

The **South Molokai** mud flats have high biodiversity and cultural and economic value, but irreversible loss of this unique site is now occurring. Earthmoving/development, feral animal grazing, and past agricultural development are eroding soil that is sedimenting the mud flats rapidly. Major losses of native species and their habitat (e.g., the endangered Hawaiian stilt) are increasing.

Because lightning is infrequent in Hawaii, fire is not a natural sustainer of ecosystems as it is on the mainland. In particular, fire is a hazard to lowland dry ecosystems in Hawaii. The damage from fire is likely to be long term. Valuable sites at higher risk include **Kokee** and **Waimea/Olukele canyon** on Kauai, **West Maui**, **Kamiloloa** on Molokai, the **Waianae range** on Oahu, and **Kanepuu** on Lanai.

FINDINGS: FULL MOLOKAI ISLAND ANALYSIS (TABLES 2-10 TO 2-13)

(All Molokai site data are in Appendix H.)

MARINE AND AQUATIC ECOSYSTEMS

A total of 20 out of the 29 ecosystem types were represented on the island of Molokai (Table 2-10). Of the 250 sites identified, 226 occurrences were rated 6 or higher in value and thus were carried forward for risk analysis. The occurrences included two offshore oceanic sites (not yet rated). Nineteen nearshore occurrences with priority scores ranging from 40 to 330 were rated, covering all nearshore waters on Molokai. Four offshore islets with priority scores ranging from 66 to 126 were rated. The fringing reefs of Molokai were divided among 10 occurrences with priority scores ranging from 190 to 594. All 34 perennial streams were rated with priority scores, varying between 108 and 500. Data were insufficient to rank

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Table 2-10. ***An overview of the status of Ecoystems comparing average Ecoscore, Stressor Scores, and Priority Scores***

	EcoSystem Type	Number of Occurrences	Average EcoScore	Average Stressor Score	Average Priority Score
01	Offshore Oceanic Areas	6	5.00	0.00	0.00
02	Nearshore Areas	24	7.42	18.62	134.46
03	Offshore Islets	6	6.00	11.50	73.00
05	Fringing Reefs	9	9.44	38.56	366.89
07	Streams	36	8.50	28.39	247.94
08	Estuaries	1	11.00	54.00	594.00
10	Fishponds	17	7.41	33.82	249.53
11	Coastlines	29	9.10	30.00	280.93
12	Anchialine pools	1	10.00	22.00	220.00
13	Freshwater lakes and reservoirs	1	7.00	26.00	182.00
15	Wetlands	18	6.72	66.22	447.17
16	Coastal herb and grasslands	18	9.22	38.56	355.22
17	Coastal shrublands	8	7.75	40.12	313.50
18	Coastal forests	5	9.40	44.20	431.80
20	Lowland dry shrubland	9	6.67	58.00	386.22
21	Lowland dry and mesic forests	28	6.04	57.61	347.79
22	Lowland wet forests and shrublands	16	7.56	50.50	381.00
23	Montane dry and mesic forests	6	7.17	42.00	301.00
24	Montane wet shrublands and forests	7	7.71	26.71	199.14
29	Lava tubes and caves	3	10.00	50.00	516.00

many streams with certainty, and ratings relied partially on the evaluations of the Hawaii Stream Assessment. Molokai's one estuary (Halawa) received a priority score of 594. Mangroves were mapped but have not yet been fully rated; a system for defining occurrences and establishing evaluative criteria is still needed. Molokai's one anchialine pool and one freshwater reservoir were rated with priority scores of 220 and 182 respectively. All 15 of Molokai's historic fishponds were rated, including those in the state fishpond study; priority scores ranged from 120 to 520. Molokai's coastlines were divided into 30 occurrences (segments), with priority scores ranging from 70 to 600. A total of 18 wetland occurrences were rated, including all those considered important by the U.S. Fish and Wildlife Service; priority scores ranged from 330 to 768.

TERRESTRIAL ECOSYSTEMS

A total of 18 occurrences of coastal herb and grasslands were rated with priority scores ranging from 192 to 473. Very little information is available for these ecosystems, and many sites could not be evaluated. The same applies to coastal shrublands, where only eight occurrences on Molokai could be rated; priority scores ranged from 180 to 504. All five known coastal forest occurrences were rated with priority scores ranging between 119 and 560. No data were available on lowland herb and grasslands. The nine lowland dry shrublands which could be identified from U.S. Fish and Wildlife Service (Jacobi) maps were rated with priority scores ranging from 306 to 462 (all high). Similarly the 19 lowland dry and mesic forests identified from the Jacobi and Nature Conservancy maps were rated with priority scores ranging from 288 to 504, most of which were high. A total of 16 occurrences for lowland wet forests and shrublands were rated with priority scores ranging from 276 to 500. The six occurrences of montane dry/mesic forests had priority scores of 252-336; and seven montane wet shrublands and forests had priority scores ranging from 147 to 287. Finally, three lava tube and cave occurrences were rated with priority scores ranging between 288 and 720. Table 2-11 lists in descending order of priority scores all 226

Table 2-11. All rated occurrences on Molokai in descending order, by priority score.

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Sheet#	Place Name	Priority Score	HERR#	Eco Type	Eco Score	Total Risk	Top 3 Stressors
97	SO. MOLOKAI MUD FLATS	768	15-MO02-K6 -	15	8	96	EM ER AL
222	KALAUPAPA CAVES	720	29-MO03-A9 -	29	12	60	AL HC EM
105	UALAPUE	700	15-MO04-K10-	15	10	70	AL ER EM
81	KAUNAKAKAI TO KAPUKALAULUA	600	11-MO03-L4 -	11	12	50	ER EM AL
44	KIPAPA TO KAOPEAHINA FP	594	05-MO04-M5 -	05	11	54	ER HC EM
47	HALAWA BAY	594	08-MO05-B7 -	08	11	54	ER HC AL
87	KIPAPA TO KAOPEAHINA FP.	583	11-MO04-M5 -	11	11	53	EM ER AL
98	KAUNAKAKAI	576	15-MO03-K4 -	15	6	96	ER EM AL
178	KIKLIPUA PT	560	18-MO05-A2 -	18	10	56	ER AL FI
180	HAKAAANO	560	18-MO05-A3 -	18	10	56	ER AL FI
223	OLD LADY'S CAVE	540	29-MO03-B10-	29	10	54	AL HC EM
54	KIPAPA	520	10-MO04-L4D-	10	8	65	AL ER EM
43	KAPUKALAULUA TO KAMAHUEHUE	517	05-MO04-LI -	05	11	47	ER NT EM
171	MOOMOMI PRESERVE	504	17-MO02-B1 -	17	12	42	ER AL FI
217	WAILAU TRAIL	504	21-MO05-HIB-	21	8	63	AL ER EM
132	WAIKOLU	500	07-MO04-0 -	07	10	50	WD ER AL
80	OOIA FISH POND TO KAUNAKAKAI	500	11-MO03-KI -	11	10	50	AL ER EM
219	PUU OHELO CLIFFS	500	22-MO05-FI -	22	10	50	ER AL TX
114	KUPEKE	490	15-MO05-J3 -	15	7	70	AL ER EM
115	WAIHILAHILA	490	15-MO05-J4 -	15	7	70	AL ER EM
112	HALAWA	480	15-MO05-B7 -	15	8	60	AL ER WD
181	PUAHAUNUI	480	18-MO05-A5 -	18	10	48	ER AL FI
163	KA LE MAU	473	16-MO03-A9 -	16	11	43	HC AL FI
248	KUKUINUI RIDGE CLIFFS	468	22-MO05-BIA-	22	9	52	ER FI AL
151	ILIO TO PUUKOAI	462	16-MO01-A5 -	16	11	42	EM AL ER
186	KAMILOLOA	462	20-MO03-K8 -	20	7	66	FI AL ER
65	KALOKOELI	462	11-MO01-A5 -	11	11	42	EM AL ER
208	NR. PUU HAHA	455	21-MO04-G6 -	21	7	65	ER AL FI
86	KAPUKALAULUIA TO KAMAHUEHUE	451	11-MO04-LI -	11	11	41	ER EM AL
207	RD TO LAPAKOHANA	450	21-MO04-HI -	21	6	75	AL FI ER
245	PAPALAUA VALLEY CLIFFS	450	22-MO05-B2 -	22	9	50	ER AL TX
201	W. OF HONUKAUKU	448	21-MO04-C6 -	21	8	56	AL ER FI
218	MAUNAOLUOLU GULCH	441	21-MO05-JI -	21	7	63	AL ER EM
116	KAWELA	440	07-MO03-0 -	07	10	44	WD ER AL
104	KAKAHAIA NWR	440	15-MO04-KI -	15	8	55	AL ER EM
117	WAIHANAU	440	07-MO03-0 -	07	10	44	WD ER AL
240	SO. OF HIST PARK BOUNDARY	440	22-MO04-C3A-	22	8	55	ER AL TX
179	WAIEHU	440	18-MO04-B9 -	18	10	44	AL ER FI
75	PAKANAKA FISH POND TO OOIA FP.	440	11-MO02-K6 -	11	10	44	ER AL HC
159	W. OF KAPALAUOA	440	16-MO02-B1 -	16	11	40	AL FI HC
158	WAIAKANAPO JTO KAPALAUOA	430	16-MO02-A1 -	16	10	43	AL ER FI
164	MAKALII	429	16-MO04-A1 -	16	11	39	AL ER HC
190	KUPAIA	427	20-MO04-EID-	20	7	61	AL FI ER
189	PUUMAKALIILII	427	20-MO04-EIB-	20	7	61	AL FI ER
192	KAPUNA SPRING	420	21-MO03-E9 -	21	7	60	AL ER FI
113	PAUWALU	420	15-MO05-H4 -	15	6	70	AL ER EM
110	KALAELOA	420	15-MO04-L9A-	15	6	70	AL ER EM
111	PUHALOA POND	420	15-MO04-L9B-	15	6	70	AL ER EM
172	PALAAU	420	17-MO02-B4 -	17	10	42	ER AL FI
109	PAIALOA	420	15-MO04-L7 -	15	6	70	AL ER EM
220	PUU LAU CLIFF TOP	414	22-MO05-F2 -	22	9	46	ER AL TX
123	HALAWA	408	07-MO05-0 -	07	12	34	WD AL ER
166	WAILAU TO HALAWA	400	16-MO05-A1 -	16	10	40	AL FI HC
41	KAUNAKAKAI TO KAPUKAULUA	400	05-MO03-M4 -	05	8	50	ER HC NT
187	MAKAKUPAIA, NR ONINI RD	396	20-MO03-K10-	20	6	66	FI AL EM
215	KANUPA TO PUNAULA GULCH	396	21-MO05-B4B-	21	6	66	ER AL FI
72	KEALAPUPUAKIHA BEACH	396	11-MO01-A7 -	11	11	36	FI AL ER
45	KALUAAHA TO KUMIMI	396	05-MO05-KI -	05	11	36	HC ER EM
156	KEALAPUPUAKIHA	396	16-MO01-A7 -	16	11	36	FI AL ER
238	WAIMANU FALLS AREA	392	22-MO04-CIB-	22	8	49	ER AL TX
200	WAIALEIA STREAM TO	392	21-MO04-B1 -	21	7	56	AL ER FI

Table 2-11. All rated occurrences on Molokai in descending order, by priority score.

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Sheet#	Place Name	Priority Score	HERR#	Eco Type	Eco Score	Total Risk	Top 3 Stressors
153	KAUNALA BAY	390	16-MO01-H3 -	16	10	39	FI HC ER
138	PELEKUNU	390	07-MO04-0 -	07	10	39	ER AL WD
161	NENEHANAUPO	387	16-MO02-B7 -	16	9	43	AL ER FI
107	PAHIOMU	385	15-MO04-L4 -	15	7	55	AL ER EM
167	HALAWA TO LAMALOA	384	16-MO05-B7 -	16	8	48	ER AL FI
42	OOIA POND TO KAUNAKAKAI	370	05-MO03-LI -	05	10	37	ER EM HC
74	KAUMANA PT TO PAKANAKA PT	368	11-MO02-LI -	11	8	46	ER AL FI
237	WAIMANU FALLS, E. TO PAPAALA	368	22-MO04-CIA-	22	8	46	ER AL TX
205	N. OF WEST FORK	366	21-MO04-GIB-	21	6	61	AL FI ER
206	NW OF LAPAKOHANA	366	21-MO04-G2A-	21	6	61	AL FI ER
188	KAUNAKAKAI/KAMALO	366	20-MO04-GIA-	20	6	61	AL FI ER
184	NW OF KUPAIA	364	20-MO03-J9A-	20	7	52	AL FI ER
183	W. OF KAULOLO	364	20-MO03-G9 -	20	7	52	AL FI ER
203	KIKIAKALA	364	21-MO04-DIA-	21	7	52	AL ER FI
185	SW OF PUU MAKALIILII	364	20-MO03-G10-	20	7	52	AL FI ER
103	PELEKUNU	360	15-MO04-B6 -	15	6	60	AL ER WD
131	WAIALEIA	360	07-MO04-0 -	07	9	40	ER AL WD
102	WAILAU	360	15-MO04-B10-	15	6	60	AL ER WD
53	PAHIOMU	360	10-MO04-L4C-	10	8	45	AL ER EM
244	PELEKUNU GULCH TO LAE O KAPUNA	357	22-MO04-H8 -	22	7	51	ER AL TX
241	KALIOLEHUULU TO KUAPUUIKI	357	22-MO04-E5 -	22	7	51	ER AL TX
243	SO. OF KUUPUKUII	357	22-MO04-G9 -	22	7	51	ER AL TX
242	KOLO RIDGE	357	22-MO04-E7 -	22	7	51	ER AL TX
239	NR. NAT. PARK BOUNDARY	357	22-MO04-B3 -	22	7	51	ER AL TX
246	KIOKIO CLIFFS	354	22-MO05-B3 -	22	6	59	ER AL TX
69	PAHIOMU	351	11-MO01-LI -	11	9	39	HC AL EM
247	LA E O LAPUNA	343	22-MO05-G1 -	22	7	49	ER AL TX
252	BELOW & E. OF KIKIAKALA	336	23-MO04-E26-	23	8	42	AL FI TX
152	PUUKOAI TO KAUNALA	336	16-MO01-F4 -	16	8	42	EM AL ER
251	E. OF KIKIAKALA	336	23-MO04-D1 -	23	8	42	AL FI TX
49	KALOKO'ELI	336	10-MO03-M6 -	10	8	42	AL ER EM
255	BELOW AND EAST OF KIKIAKALA	336	23-MO04-E2A-	23	8	42	AL FI TX
197	KAMILOLOA	336	21-MO03-J9D-	21	7	48	AL FI ER
39	KAUMANA PT TO OOIA FISHPOND	333	05-MO02-LI -	05	9	37	ER NT TX
106	UALAPUE	330	15-MO04-L5 -	15	6	55	AL ER EM
101	KAWELA	330	15-MO03-N10-	15	6	55	AL ER EM
100	KANOA POND	330	15-MO03-N9 -	15	6	55	AL ER EM
99	ALII FISHPOND	330	15-MO03-M8 -	15	6	55	AL ER EM
77	PT WOF KAPALAUOA TO NAAUKAHIHI	330	11-MO02-B1 -	11	11	30	AL FI HC
67	KANOA	330	11-MO01-H3 -	11	10	33	HC ER AL
193	KAPUNA	330	21-MO03-F8 -	21	6	55	AL FI ER
194	W. OF KAULOLO	330	21-MO03-G8 -	21	6	55	AL FI ER
160	KA LE MAU TO MAKALII	330	16-MO02-B4 -	16	10	33	AL ER EM
58	UALAPU'E	330	10-MO04-L10-	10	10	33	ER AL EM
209	PUU HAHA E.TO MAPULEHU	330	21-MO04-H6 -	21	6	55	AL FI ER
12	OOIA FISHPOND TO KAUNAKAKAI	330	02-MO03-KI -	02	6	55	ER AL NT
150	KAMALO	330	07-MO04-0 -	07	10	33	ER AL EM
154	KAUNALA TO LAAU	322	16-MO01-H3 -	16	7	46	FI ER AL
59	KUPEKE	320	10-MO05-J3B-	10	8	40	EM ER AL
175	HAUPU	312	17-MO04-B4 -	17	8	39	ER FI AL
90	KALUAAHA TO KUMIMI	312	11-MO05-KI -	11	12	26	EM HC ER
165	KUKAIWAA PT	312	16-MO04-B3 -	16	8	39	AL ER HC
204	S. OF PUU MAKALIILII	312	21-MO04-EIC-	21	6	52	AL ER FI
191	WAIHII	312	21-MO03-E8 -	21	6	52	AL FI EM
127	WAIALUA	308	07-MO05-0 -	07	11	28	ER AL EM
182	KAUNAKAKAI GULCH TO QUAD BOUND	306	20-MO03-F7 -	20	6	51	AL FI ER
249	HALAWA SLOPES OVER 600 M	306	22-MO05-BIB-	22	6	51	ER AL TX
126	HONOULIWAI	297	07-MO05-0 -	07	11	27	ER AL EX
70	KALOKOIKI	294	11-MO01-M6 -	11	6	49	ER AL FI
253	PUU HAHA	294	23-MO04-G6B-	23	7	42	AL FI TX
170	WAIAKANAPE TO MOOMOMI	294	17-MO02-A1 -	17	7	42	ER AL FI

Table 2-11. All rated occurrences on Molokai in descending order, by priority score.

Date: 09-28-92

Sheet#	Place Name	Priority Score	HERR#	Eco Type	Eco Score	Total Risk	Top 3 Stressors
169	WAIAKANAPE	294	17-MO01-B10-	17	7	42	ER AL FI
144	WAILAU	290	07-MO04-0 -	07	10	29	AL ER WD
224	KAMAKO PIPING CAVE	288	29-MO04-F5 -	29	8	36	TX AL HC
130	MAPULEHU	288	07-MO05-0 -	07	9	32	TX AL ER
195	SO. FORK AREA	288	21-MO03-H9 -	21	6	48	AL ER FI
196	MAKAKUPAIA 2	288	21-MO03-J9B-	21	6	48	AL FI ER
261	NR. PUU OHELO AT 1000M	287	24-MO05-D2 -	24	7	41	ER AL TX
236	W. OF wAIMANU FALLS	276	22-MO03-F10-B	22	6	46	ER AL TX
83	PUWAHI TO KA LAEA	275	11-MO03-C7 -	11	11	25	AL HC ER
93	HALAWA BAY	270	11-MO05-B7 -	11	10	27	AL ER EM
168	LAMALOA TO WAILUA ST.	270	16-MO05-B9 -	16	6	45	ER AL FI
48	Kalua'apuhi	264	10-MO03-KI -	10	8	33	AL ER EM
38	LONO HARBOR TO KOLOWHARF	264	05-MO01-M6 -	05	8	33	ER HC EM
118	PAPIO	264	07-MO05-0 -	07	8	33	ER AL TX
149	WAWAIA	264	07-MO04-0 -	07	8	33	ER AL WD
51	KANOA	259	10-MO03-M9 -	10	7	37	ER EM HC
121	KAWAINUI	256	07-MO05-0 -	07	8	32	ER AL EX
91	KUMIMI TO KANAHA	252	11-MO05-G7 -	11	9	28	ER EM HC
174	MANEOPAPA	252	17-MO03-C1 -	17	6	42	ER AL FI
250	TOP OF KAPAPA PALI	252	23-MO04-C7 -	23	6	42	AL FI TX
254	WEST OF KALAPAMOA RIDGE	252	23-MO04-H7 -	23	6	42	AL FI TX
173	NENEHANAUPO	252	17-MO02-B7 -	17	6	42	ER AL FI
76	WAIAKANAPO TO W. OF KAPALAUOA	250	11-MO02-A1 -	11	10	25	AL HC ER
13	KAUNAKAKAI TO KAPUKAULUA	248	02-MO03-L4 -	02	8	31	EM NT ER
260	MAJOR 1000M SUMMIT	246	24-MO05-D1 -	24	6	41	ER AL TX
55	KALOKOIKI	245	10-MO04-L7B-	10	7	35	EM AL ER
125	HONOULIMALOO	243	07-MO05-0 -	07	9	27	ER AL EX
137	KAILIILI	243	07-MO04-0 -	07	9	27	ER AL EX
143	WAILELE	240	07-MO04-0 -	07	10	24	ER AL EX
37	LAAU PT TO KAPUKAWAHINE	238	05-MO01-LI -	05	7	34	HC ER NT
66	KAOINI	231	11-MO01-F4 -	11	7	33	AL FI ER
162	ANIANIKEHA	225	16-MO03-C1 -	16	9	25	AL FI ER
71	KAINAOHE	224	11-MO01-A8 -	11	8	28	ER AL HC
62	KA'OPEAHINA	224	10-MO05-KI -	10	8	28	AL ER EM
95	KAUHAKO CRATER	220	12-MO03-C9 -	12	10	22	AL HC TX
145	KALUAAHA	216	07-MO04-0 -	07	8	27	ER AL TX*
157	E. KEALAPUPUAKIHA TO WAIAKAPAN	216	16-MO01-A8 -	16	8	27	ER AL FI
128	KAINALU	216	07-MO05-0 -	07	9	24	AL ER EM
147	MANAWAI	216	07-MO04-0 -	07	8	27	ER AL TX
134	ANAPUHI	216	07-MO04-0 -	07	8	27	ER AL EX
8	Kaunala Bay S. to Laau Pt	216	02-MO01-H3 -	02	8	27	HC ER EM
148	OHIA	216	07-MO04-0 -	07	8	27	ER AL TX
141	OLOUPENA	210	07-MO04-0 -	07	10	21	ER AL EX
257	CLIFFS E. OF KALAPUEO	210	24-MO04-D2 -	24	10	21	AL TX EX
60	KAHIALOKO	210	10-MO05-J4B-	10	7	30	ER AL EM
146	KAHANANUI	203	07-MO04-0 -	07	7	29	ER AL WD
129	HONOMUNI	192	07-MO05-0 -	07	8	24	AL ER EM
155	ILIO TO KEALAPUPUAKIHA	192	16-MO01-A5 -	16	8	24	ER AL EX
140	HALOKLU	192	07-MO04-0 -	07	8	24	ER AL EX
73	ILIO PT TO KEALAPUPUAKIHA	192	11-MO01-A5 -	11	8	24	AL FI HC
46	KUMIMI TO KANAHA	190	05-MO05-G7 -	05	10	19	HC EM ER
136	KEAWANUI	189	07-MO04-0 -	07	7	27	ER AL EX
10	CFS 314	189	02-MO04-M7 -	02	7	27	HC ER EM
135	WAIOHOOKALO	189	07-MO04-0 -	07	7	27	ER AL EX
133	WAINENE	189	07-MO04-0 -	07	7	27	ER AL EX
94	MILO PT TO HALAWA BAY	184	11-MO05-A1 -	11	8	23	AL ER EX
96	KUALAPUU RESERVOIR	182	13-MO03-E2 -	13	7	26	ER EM GC
57	KEAWANUI	180	10-MO04-L8B-	10	9	20	AL ER EM
6	Puu Koai to Kaunala Bay	180	02-MO01-F4 -	02	9	20	ER HC EM
176	KAHOLAIKI BAY	180	17-MO04-B6 -	17	6	30	FI AL TX
7	Kaunala Bay	171	02-MO01-G3 -	02	9	19	ER EM HC

Table 2-11. ***All rated occurrences on Molokai in descending order, by priority score.***

Date: 09-28-92

Sheet#	Place Name	Priority Score	HERR#	Eco Type	Eco Score	Total Risk	Top 3 Stressors
139	WAIPU	168	07-MO04-0 -	07	7	24	ER AL EX
221	KAPAPA PALI	168	24-MO04-C7 -	24	8	21	AL TX EX
258	OHIALELE	168	24-MO04-D4 -	24	8	21	AL TX EX
256	ALL UPLAND FLAT AREA	168	24-MO04-C3B-	24	8	21	AL TX EX
142	PUUKAOKU	168	07-MO04-0 -	07	8	21	ER AL EX
120	KAHIWA	162	07-MO05-0 -	07	9	18	ER TX EX
9	CFS311	162	02-MO03-KI -	02	6	27	HC ER EM
30	ILIO PT TO W KEALAPUPUAKIHA	162	02-MO01-A5 -	02	9	18	HC ER HT
124	POHAKUPILI	162	07-MO05-0 -	07	6	27	ER AL EX
68	KAWIU	162	11-MO01-H3 -	11	6	27	AL FI EM
61	WAIHILAHILA	161	10-MO05-J4C-	10	7	23	ER AL EX
78	NAAUKAHIHI TO ANIANIKEHA	160	11-MO02-B4 -	11	10	16	AL ER EX
17	HALAWA BAY	160	02-MO05-B8 -	02	10	16	ER NT EX
26	PT 1/2 MI WOF KAPALAUNOA TO ?	160	02-MO02-B1 -	02	10	16	HC ER HT
50	KAOINI	154	10-MO03-M8C-	10	7	22	AL ER EX
259	PUU ALII TO E. OF KILAU	147	24-MO04-E5 -	24	7	21	AL TX EX
52	KAWI'U	144	10-MO04-L2 -	10	6	24	ER AL EX
119	WAIAHOOKALO	126	07-MO05-0 -	07	7	18	ER TX EX
31	MOKAPU	126	03-MO04-A2 -	03	7	18	HC FI AL
23	KAPUAHIAPELE TO PUWAKI	126	02-MO03-C6 -	02	9	14	ER HC EX
56	KAINA'OHE	120	10-MO04-L8A-	10	8	15	ER AL EM
88	WAINENE TO MILO PT	120	11-MO04-B3 -	11	6	20	AL ER EX
177	HUELO ROCK	119	18-MO04-B3 -	18	7	17	AL TX FI
22	PUWAKI TO KA LAEA	112	02-MO03-C7 -	02	8	14	HC ER EM
5	Ilio Pt to Puu Koai	112	02-MO01-A5 -	02	8	14	ER NT EX
32	OKALA	108	03-MO04-A2B-	03	6	18	AL GC HC
16	KANAHA TO HALAWA BAY	105	02-MO05-F8 -	02	7	15	HC EX FI
18	MILO PT TO HALAWA BAY	105	02-MO05-A1 -	02	7	15	ER HC EX
29	KEALAPUPUAKIHA BEACH	98	02-MO01-A7 -	02	7	14	HC WD ER
34	MOKUHOONIKI	98	03-MO05-E10-	03	7	14	FI HC AL
85	ANIANIKEHA TO KAPUAHIAPELE	91	11-MO03-C1 -	11	7	13	AL ER EX
89	MAKALII MOKO-TO WAINENE	84	11-MO04-A1 -	11	7	12	ER AL EX
92	KANAHA TO HALAWA BAY	84	11-MO05-F8 -	11	6	14	EM AL ER
84	KAPUAHIAPELE TO PUWAHI	81	11-MO03-C6 -	11	9	9	ER AL HC
27	WAIAKANAPO TO PT WOF KAPALAUOA	72	02-MO02-A1 -	02	6	12	HC ER EM
82	KA LAIA TO MAKALII MOKIO	70	11-MO03-A8 -	11	10	7	ER AL EM
33	HUELO ROCK	66	03-MO04-B3 -	03	6	11	TX AL EX
19	WAINENE TO MILO PT	56	02-MO04-B3 -	02	7	8	HC ER EX
21	KA LAIA TO MAKALII MOKIO	48	02-MO03-A8 -	02	8	6	HC ER HT
20	MAKALII MOKIO TO WAINENE	40	02-MO04-A1 -	02	10	4	ER EX FI
230	CFS 331	0	01-MO01-0 -	01	7	0	EX FI GC
232	CFS 321	0	01-MO01-0 -	01	6	0	EX FI GC

Table 2-12
Molokai's Threatened Ecosystems

Ecosystem Type	Sites Moderately to Severely Threatened (%)
Nearshore waters	5
Fringing reefs	60
Streams	15
Estuary (one only)	100
Fishponds	33
Coastline segments	36
Wetlands	100
Coastal herb and Grasslands	77
Coastal shrublands	87
Coastal Forests	80
Lowland ecosystems	100
Montane ecosystems	62
Lava Tube/caves	100

See Table 2-11.

occurrences rated for the Molokai analysis, including risk scores, ecoscores, the top three stressors, and place names.

THREATENED ECOSYSTEMS

A risk score of 35 or more for any ecosystem occurrence is considered moderate to severe (see Table 2-12).

TOP PRIORITY ECOSYSTEM OCCURRENCES

A total of 55 ecosystem occurrences on Molokai (over 24%) had exceptionally high priority scores (400 or more), indicative of valuable ecosystem sites at high risk (Table 2-11). These included 3 fringing reefs, 4 streams, the one estuary, one fishpond, 7 coastlines, 11 wetlands, 12 coastal ecosystem sites, 14 lowland ecosystem sites, and 2 lava tube occurrences. More than one-half (120) of the rated ecosystem occurrences had priority scores of 300 or more. The place names of all these occurrences are listed in Table 2-11.

STRESSORS ON MOLOKAI'S ECOSYSTEMS

Table 2-13 lists the impact of various stressors on each ecosystem occurrence on Molokai. For valuable nearshore ecosystems and fringing reefs, soil erosion/sedimentation, human crowding/overfishing, and earthmoving/development were the three most important, and the first two were listed as a stressor in 80-90% of the sites. Nutrients and toxic substances were also rated as important stressors to fringing reefs. Fire, human crowding, and alien species were the top three stressors noted for the offshore islets, although the level of risk appears low. Soil erosion and alien species were overwhelmingly important stressors to streams, with water diversion/channelization a distant third. The first two stressors were listed as a risk in 90-100% of the streams. Earthmoving/development and toxic substances were also important stressors on streams, and generally the same stressors showed the most risk to Molokai's one rated estuary (Halawa). Soil erosion/sedimentation and alien species were the most important to fishponds, and both were noted as stressors on 100% of the occurrences. Earthmoving/development was a distant third in importance as a stressor. The same three stressors accounted for the most risk to wetlands and coastlines, with both alien species and soil erosion noted on 90-100% of the occurrences. In addition, human crowding and fire also constituted significant risks to coastline sites.

For terrestrial ecosystems, the three most important stressors were alien species, soil erosion, and fire. Alien species as a threat was noted on 100% of the coastal land sites and soil erosion noted on 95% of the sites. Fire was nearly as important and noted on 90% or more of the coastline segments. Human crowding and earthmoving/development were also important stressors to coastal lands. In Molokai's lowlands, the most important stressors were alien species, fire, and soil erosion, in that order; all were noted to some degree at 100% of the sites. Earthmoving/development and toxic substances were also frequently mentioned as stressors. For montane ecosystems, alien species was the major stressor, followed by fire and toxic chemicals (see Table 2-13). For lava tubes, the most important

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92
Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
Nearshore Areas												
5					9						4	1
6				4	12				4			
7					9	4	4	4	4		6	
8				4	8				15			
9				4	8				15			
10				4	8				15			
11				12	20				15			
12	20	6	10	9	25							
13			10	12	9							
16									15			
17			4		12							
18					9				6			
19					4				4			
20					4							
21					2				4			
22				2	4				8			
23					8				6			
24					8				8			
26					4				12			
27					4				8			
28					4				8			
29						2			12			
30					8				10			
Total:	20	6	24	51	179	6	4	4	169		10	1
Average:	1.00	0.30	1.20	2.55	8.95	0.30	0.20	0.20	8.45	0.00	0.50	0.05
Offshore Islets												
31	4								8		6	
32	12								3	3		
33	5	6										
34	4								4		6	
36	8											
Total:	33	6							15	3	12	
Average:	8.25	1.50	0.00	0.00	0.00	0.00	0.00	0.00	3.75	0.75	3.00	0.00
Fringing Reefs												
37			4		15				15			
38		4		6	15				12			
39		2	10		25							
41			15	6	20				15			
42		8	9	12	15				10			
43			15	8	24							

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92
Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
44	6			12	24				18			
45				6	15				15			
46				4	3				12			
Total:	6	14	53	54	156				97			
Average:	0.67	1.56	5.89	6.00	17.33	0.00	0.00	0.00	10.78	0.00	0.00	0.00

Streams

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
116	12				12	20						
117	12	6			12	20						
118	12	6			15							
119		6			12							
120		6			12							
121	12				20							
122	12				15							
123	12	6		6	10	12						
124	12				15							
125	12				15							
126	12				15							
127	12			4	12							
128	12			4	8							
129	12			4	8							
130	12	12		8	8							
131	15				15	10						
132	15	2		6	15	20						
133	12				15							
134	12				15							
135	12				15							
136	12				15							
137	12				15							
138	12				15	12						
139	9				15							
140	9				15							
141	9				12							
142	9				12							
143	9				15							
144	15				8	6						
145	9	6			12							
146	9	6			12	8						
147	9	6			12							
148	9	6			12							
149	12	6			15	6						
150	12			6	15							
Total:	378	74		38	464	114						
Average:	11.12	2.18	0.00	1.12	13.65	3.35	0.00	0.00	0.00	0.00	0.00	0.00

Estuaries

Table 2-13. *Impacts of various stressors on each rated occurrence on Molokai* Date: 09-28-92
Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
47	15	4		9	24	6			15			
Total:	15	4		9	24	6			15			
Average:	15.00	4.00	0.00	9.00	24.00	6.00	0.00	0.00	15.00	0.00	0.00	0.00

Fishponds

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
48	15			8	10							
49	15			12	15							
50	12				10							
51	9			12	15				10			
52	9				15							
53	15			15	15							
54	30			15	20							
55	10			15	10							
56	5				10							
57	10				10							
58	10			8	15							
59	10			15	15							
60	10				20							
61	5				18							
62	10			8	10							
63	5			8	15							
64	20			15	20							
Total:	200			131	243				10			
Average:	13.33	0.00	0.00	8.73	16.20	0.00	0.00	0.00	0.67	0.00	0.00	0.00

Coastlines

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
65	15	4		15	12				10			
66	15			6	9						9	
67	9		4		12				12			
68	15			6							6	
69	15			9					15			
70	15				25						9	
71	12				12				4		3	
72	12			6	9						15	
73	12			6	4				6		6	
74	15			6	25						6	
75	20				20				4			
76	12				4				9		2	
77	16				1		6		6		8	
78	12				4							
80	20			15	15				12			
81	15			15	20							
82	2			1	4							
83	9				8				8			
84	4				4				1			
85	9				4							

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92
Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
86	9			12	20							
87	15			20	18							
88	12				8							
89	4				8							
90				12	6				8			
91				12	12				4			
92	6			6	2							
93	12			6	9							
94	15				8							
Total:	327	4	4	153	283		6		99		64	
Average:	11.28	0.14	0.14	5.28	9.76	0.00	0.21	0.00	3.41	0.00	2.21	0.00

Anchialine pools

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
95	8	6							8			
Total:	8	6							8			
Average:	8.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00	0.00	0.00	0.00

Freshwater lakes and reservoirs

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
96	2	1	4	10	10	4	4	4	6	6	1	1
Total:	2	1	4	10	10	4	4	4	6	6	1	1
Average:	2.00	1.00	4.00	10.00	10.00	4.00	4.00	4.00	6.00	6.00	1.00	1.00

Wetlands

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
97	24			36	36							
98	24			36	36							
99	25			15	15							
100	25			15	15							
101	25			15	15							
102	25				20	15						
103	25				20	15						
104	25			15	15							
105	30			15	25							
106	25			15	15							
107	25			15	15							
109	30			15	25							
110	30			15	25							
111	30			15	25							
112	25				20	15						
113	30			15	25							
114	30			15	25							
115	30			15	25							
Total:	483			267	397	45						
Average:	26.83	0.00	0.00	14.83	22.06	2.50	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92
Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Coastal herb and grasslands

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
151	15	4		15	12				10			
152	15	4			12				8			15
153	9		4		12				12		15	
154		6		8	15		15				16	
155	12				12							
156	12			6	9						15	
157	12				12						3	
158	16			6	15						12	
159	16			6	1				12		12	
160	15			6	12							
161	16			6	15						12	
162	15			1	4						6	
163	15			4	4				16		12	
164	16				15				8		6	
165	16				15				8		6	
166	16				12				12		12	
167	16	4		8	20				12		12	
168	16			9	20				6		9	
Total:	248	18	4	75	217		15		104		148	15
Average:	13.78	1.00	0.22	4.17	12.06	0.00	0.83	0.00	5.78	0.00	8.22	0.83

Coastal shrublands

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
169	15				15				9		12	
170	15				15				9		12	
171	15			6	15				12		12	
172	15			6	15				12		12	
173	15				15						12	
174	15				15						12	
175	12	6			15						12	
176	12	6									12	
Total:	114	12		12	105				42		96	
Average:	14.25	1.50	0.00	1.50	13.12	0.00	0.00	0.00	5.25	0.00	12.00	0.00

Coastal forests

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
177	8	6									3	
178	24				24				4		8	
179	20				16				4		8	
180	24				24				4		8	
181	20				20				4		8	
Total:	96	6			84				16		35	
Average:	19.20	1.20	0.00	0.00	16.80	0.00	0.00	0.00	3.20	0.00	7.00	0.00

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92
Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
Lowland dry shrubland												
182	24	6		12	12						15	
183	24	6			12						16	
184	24	6			12						16	
185	24	6			12						16	
186	24	6		12	12						30	
187	24	6		12	6						30	
188	30	6		12	15						16	
189	30	6			15						16	
190	30	6			15						16	
Total:	234	54		48	111						171	
Average:	26.00	6.00	0.00	5.33	12.33	0.00	0.00	0.00	0.00	0.00	19.00	0.00
Lowland dry and mesic forests												
191	24	6		12							16	
192	24	9			20						16	
193	24	6			15						16	
194	24	6			15						16	
195	24	6			12						12	
196	24	6			12						12	
197	24	6			12						12	
198	24	6			12						12	
199	24	6			12						12	
200	24	6			20						12	
201	24	6			20						12	
202	24	6			20						12	
203	24	6			16						12	
204	24	6			16						12	
205	30	6			15						16	
206	30	6			15						16	
207	36	6			15						24	
208	24	6			25						16	
209	24	6			15						16	
210	24	6		8	20						16	
211	24	6		8	20						16	
212	25	6			20						16	
213	25	6			25						12	
214	25	6			25						16	
215	25	6			25						16	
216	25	6			20						16	
217	25	6		18	20						16	
218	25	6		18	20						4	
Total:	703	171		64	482						400	
Average:	37.00	9.00	0.00	3.37	25.37	0.00	0.00	0.00	0.00	0.00	21.05	0.00

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92

Total = Stressor risk score for all occurrences in that ecosystem type

Average = Average stressor score per occurrence in that ecosystem type

Lowland wet forests and shrublands

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
219	20	6			24						4	
220	20	6			20						4	
236	20	6			20						4	
237	20	6			20						4	
238	20	9			20						4	
239	20	6			25						4	
240	20	10			25						4	
241	20	6			25						4	
242	20	6			25						4	
243	20	6			25						4	
244	20	6			25						4	
245	20	6			24						4	
246	20	15			24						4	
247	20	9			20						4	
248	16	6			20						16	
249	20	6			25						4	
Total:	316	115			367						76	
Average:	19.75	7.19	0.00	0.00	22.94	0.00	0.00	0.00	0.00	0.00	4.75	0.00

Montane dry and mesic forests

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
250	24	6									12	
251	24	6									12	
252	24	6									12	
253	24	6									12	
254	24	6									12	
255	24	6									12	
Total:	144	36									72	
Average:	24.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.00	0.00

Montane wet shrublands and forests

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
221	15	6										
256	15	6										
257	15	6										
258	15	6										
259	15	6										
260	15	6			20						4	
261	15	6			20						4	
Total:	105	42			40						8	
Average:	15.00	6.00	0.00	0.00	5.71	0.00	0.00	0.00	0.00	0.00	1.14	0.00

Lava tubes and caves

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
222	36			12					12			

Table 2-13. ***Impacts of various stressors on each rated occurrence on Molokai*** Date: 09-28-92

Total = Stressor risk score for all occurrences in that ecosystem type

Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
223	30			12					12			
224	12	18							6			
Total:	78	18		24					30			
Average:	26.00	6.00	0.00	8.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	0.00

stressors were noted to be alien species, human crowding, and earthmoving/development, with toxic substances also a risk.

Stressor data are summarized in Table 2-14 in matrix form; the sum total of all stressor scores is provided for each combination of ecosystem type and stressor. Overall, the two most important stressors on natural ecosystems on Molokai are alien species and soil erosion/sedimentation. These two stressors were significant risks in both aquatic/marine and terrestrial ecosystems. The next in importance as stressors were earthmoving/channelization and fire. Fire ranked third in importance for terrestrial ecosystems, while earthmoving/development was third in importance in aquatic/marine ecosystems. Other important stressors were water diversion (wetlands, fishponds, streams) and human crowding/overfishing in both marine and coastal terrestrial ecosystems. Nutrient/biochemical oxygen demand appears not to be a significant stressor on Molokai, probably due to the island's low human population level and sewage discharges (see Table 2-14).

STRESSOR SEVERITY CHARACTERISTICS FOR MOLOKAI

Alien species have a great impact on terrestrial ecosystems and usually cause damage that is only recoverable over a long time period.

Erosion and earthmoving cause severe sedimentation in nearshore waters, streams, estuaries, and wet lowlands. The damage is usually substantial with a long recovery time.

Fire damage is concentrated on dry grass, shrub, and forest lands.

Human crowding affects mainly coastal areas and only partial loss of uses of the resource are usually incurred. Recovery may be rapid if the stress is removed.

Toxic chemicals affect animals in local and aquatic ecosystems. Damage may be moderate but a long recovery time is necessary if the toxic materials persist in sediment or are recycled in the food web.

Table 2-14. Impacts of various stressors on each ecosystem type on Molokai Date: 09-28-92

Total = Stressor risk score for all occurrences in that ecosystem type
Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
Nearshore Areas												
Total:	20	6	24	51	179	6	4	4	169		10	1
Average:	1.00	0.30	1.20	2.55	8.95	0.30	0.20	0.20	8.45	0.00	0.50	0.05
Offshore Islets												
Total:	33	6							15	3	12	
Average:	8.25	1.50	0.00	0.00	0.00	0.00	0.00	0.00	3.75	0.75	3.00	0.00
Fringing Reefs												
Total:	6	14	53	54	156				97			
Average:	0.67	1.56	5.89	6.00	17.33	0.00	0.00	0.00	10.78	0.00	0.00	0.00
Streams												
Total:	378	74		38	464	114						
Average:	11.12	2.18	0.00	1.12	13.65	3.35	0.00	0.00	0.00	0.00	0.00	0.00
Estuaries												
Total:	15	4		9	24	6			15			
Average:	15.00	4.00	0.00	9.00	24.00	6.00	0.00	0.00	15.00	0.00	0.00	0.00
Fishponds												
Total:	200			131	243				10			
Average:	13.33	0.00	0.00	8.73	16.20	0.00	0.00	0.00	0.67	0.00	0.00	0.00
Coastlines												
Total:	327	4	4	153	283		6		99		64	
Average:	11.28	0.14	0.14	5.28	9.76	0.00	0.21	0.00	3.41	0.00	2.21	0.00
Anchialine pools												
Total:	8	6							8			
Average:	8.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00	0.00	0.00	0.00
Freshwater lakes and reservoirs												
Total:	2	1	4	10	10	4	4	4	6	6	1	1
Average:	2.00	1.00	4.00	10.00	10.00	4.00	4.00	4.00	6.00	6.00	1.00	1.00
Wetlands												
Total:	483			267	397	45						
Average:	26.83	0.00	0.00	14.83	22.06	2.50	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-14. Impacts of various stressors on each ecosystem type on Molokai Date: 09-28-92

Total = Stressor risk score for all occurrences in that ecosystem type

Average = Average stressor score per occurrence in that ecosystem type

Sheet#	Alien	Toxic	Nutri	Emove	Erosn	Water	Noise	Heat	Human	Globl	Fire	Explo
Coastal herb and grasslands												
Total:	248	18	4	75	217		15		104		148	15
Average:	13.78	1.00	0.22	4.17	12.06	0.00	0.83	0.00	5.78	0.00	8.22	0.83
Coastal shrublands												
Total:	114	12		12	105				42		96	
Average:	14.25	1.50	0.00	1.50	13.12	0.00	0.00	0.00	5.25	0.00	12.00	0.00
Coastal forests												
Total:	96	6			84				16		35	
Average:	19.20	1.20	0.00	0.00	16.80	0.00	0.00	0.00	3.20	0.00	7.00	0.00
Lowland dry shrubland												
Total:	234	54		48	111						171	
Average:	26.00	6.00	0.00	5.33	12.33	0.00	0.00	0.00	0.00	0.00	19.00	0.00
Lowland dry and mesic forests												
Total:	703	171		64	482						400	
Average:	37.00	9.00	0.00	3.37	25.37	0.00	0.00	0.00	0.00	0.00	21.05	0.00
Lowland wet forests and shrublands												
Total:	316	115			367						76	
Average:	19.75	7.19	0.00	0.00	22.94	0.00	0.00	0.00	0.00	0.00	4.75	0.00
Montane dry and mesic forests												
Total:	144	36									72	
Average:	24.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.00	0.00
Montane wet shrublands and forests												
Total:	105	42			40						8	
Average:	15.00	6.00	0.00	0.00	5.71	0.00	0.00	0.00	0.00	0.00	1.14	0.00
Lava tubes and caves												
Total:	78	18		24					30			
Average:	26.00	6.00	0.00	8.00	0.00	0.00	0.00	0.00	10.00	0.00	0.00	0.00

STRESSOR FREQUENCY CHARACTERISTICS FOR MOLOKAI

Alien species is by far the greatest ongoing, increasing stressor, not some future hazard, and urgent action is necessary.

Erosion is also a current and increasing stressor to aquatic and lowland ecosystems.

Earthmoving impacts are plausible for the near future at a large number of lowland and wetland sites.

Fire is an occasional threat and is often purposely set by vandals.

Human crowding is occasional to continual in likelihood of occurrence.

Toxic materials stress is plausible at this time but preventive measures taken now should be cost-effective.

DESCRIPTION OF SPECIFIC MOLOKAI ECOSYSTEM SITES AT SUBSTANTIAL RISK

The six highest-priority sites on Molokai were the wetlands at Ualapue and South Molokai mud flats (occurrences #97 and #105), the lava tubes at Kalaupapa Caves (occurrence #222), the coastline between Kaunakakai and Kapukalaulua (occurrence #81), the fringing reef between Kipapa and Kaopeahina (#44), and the estuary at Halawa (#47).

Wetlands

Both high-priority wetlands (Ualapue and S. Molokai) are threatened by soil erosion, earthmoving/development, and alien species encroachment. As with other islands, these wetlands are important habitat for endangered waterbirds and serve as sediment and water pollution filters of benefit to coastal waters. These wetlands also serve important water recharge and flood control functions. Essentially all wetlands on Molokai are at significant risk, even those already designated as parks and refuges.

Lava Tube at Kalaupapa Cave

Lava tubes located near human population areas or lands proposed for development and cultivation are threatened primarily by destruction from alien species and human disturbance and development. These ecosystems contain unique species of dryland and aquatic insects, spiders, and other organisms adapted to cave habitats. Alteration of habitat (around or within the cave) or introduction of fire, light, weeds, feral ungulates, and predators can drastically alter lava tube ecosystems. Subterranean systems dependent on underground streamflow are particularly vulnerable to toxic chemicals leached from the watershed to caves below. The proposed fruit fly eradication program may involve pesticides that could be a hazard to these systems.

Fringing Reefs and Coastlines

The fringing reef between Kipapa and Kaopeahina along Molokai's south coast is representative of the threats to which these important ecosystems are subjected. A century of agriculture, ranching, and overgrazing of ground cover by introduced game animals has eroded soils and caused mass-wasting and sedimentation of coastal areas. Although agriculture is no longer the immediate cause of damage, much of the sediment is still accumulated on inner reef flats and shorelines, degrading habitat and other values, including fishing and recreation. Mangroves (as an alien species) are also colonizing many of the mudflats, displacing reef flats and converting beach shorelines into swamp fringes. Coastline and fringing reef areas adjacent to settlements are also faced with other stressors, including nutrient pollution, toxic substances, and the threat of earthmoving/development and crowding/overfishing.

Halawa Estuary

At the east end, Halawa stream and estuary offer a full range of values, including scenic, cultural, recreational, visitor, and ecological uses. Soil erosion from feral animals upland in the watershed and alien species are particularly important stressors, and overfishing/human crowding looms as a future major threat. Halawa is a popular destination area for both visitors and residents.

Coastal and Lowland Terrestrial Forests, Scrub, Grass, Herb and Fernlands

Over the past century, deer and goats released into vegetated lands have continued to ravage lowland and dryland areas, while these and pigs have also trampled and disturbed upland mesic and wetter areas. Removal of soil and groundcover causes sedimentation downstream and facilitates successful invasion by alien weeds and pests. At lower and dryer elevations, fire and agricultural development have also denuded groundcover or replaced native plant communities with exotic-dominated communities. Some lowland and most coastlands are also vulnerable to urban development. On a statewide basis, lowland and coastland areas have not been well-inventoried, although data for Molokai are more comprehensive than for most other islands. Due to their proximity to humans, development, and agriculture, virtually all remaining native lowland and coastal ecosystems are at severe risk on Molokai, and it is an urgent priority to inventory the status of remaining stands not only on Molokai but statewide.

COMPARISON OF FINDINGS OF ONE HUNDRED SITES AND MOLOKAI ANALYSIS

Both analyses clearly demonstrate the importance of alien species and soil erosion/sedimentation as the major threats to native ecosystems in Hawaii. Earthmoving/development, human crowding/over-fishing and nutrients/biochemical oxygen demand are also consistently important stressors, based upon the results of both analyses, but the level of impacts on Molokai are slightly lower than levels statewide due to the lower human populations on the Friendly Island. However, the dryer climate on much of Molokai exacerbates the threat of fire.

The Molokai analysis also documents that native lowland and coastland terrestrial ecosystems are at risk of being completely depleted from the island due to the multitude of stressors affecting them. In addition the island's southern coastlines, fishponds, wetlands, and fringing reefs are all under siege from eroded soils, alien species, and other conflicts with human use and development patterns. These trends are expected to apply to the other main islands of Hawaii.

The large proportion of sites on Molokai with priority scores exceeding 300 (well over 100 occurrences) indicates that a full-state analysis of all islands is essential for mapping and locating ecosystem occurrences at high risk. In addition, a number of the Molokai sites had priority scores above 400, indicating that many of the threatened sites are of very high value. The one hundred sites analysis provides an accurate indication of the specific stressors and their relative importance statewide in threatening ecosystems.

NUTRIENTS AS STRESSORS

The introduction of nutrients (nitrogen and phosphorous) into nearshore waters can cause aquatic plants (algae and seaweed) to increase rapidly in mass since one of these elements is likely a limiting factor in growth. This additional plant matter can decrease the clarity of ocean water, thus interfering with snorkeling, diving, and swimming recreation. Furthermore, the seaweed mass can accumulate in large volumes to clog harbors and pile up on shores, rotting and producing foul odors.

The nutrients enter the coastal waters from overland runoff from croplands, golf courses, urban areas, and cattle operations. They also come from sewage treatment plants that discharge effluent into wells (DOH news release, Feb. 21, 1992) or from overflowing septic tanks. These sewage effluents move through the ground to the ocean, usually entering at shallow depths.

Algae and seaweed respond strongly to even small additions of nutrients, increasing their rate of growth. Sewage effluent can contain 100 times the amount of phosphorous that is normally in the ocean. Once the nutrients are taken up in increased plant growth, they remain in the coastal environment for a long time, recycling when the seaweed dies. As the plant matter decays, the nutrients are released and immediately taken up by new growth. Thus, even stopping the nutrients at their source may not remedy the nearshore damage from seaweed for many years.

A "red" seaweed intentionally brought to Hawaii for aquaculture is an example of an alien species as stressor combined with the nutrient stressor. This plant (Eucheuma) was introduced into Kaneohe Bay in the early 1970s. Another seaweed (Cladophora) is now found off Lahaina in Maui in damaging amounts and is expected to appear on the Big Island, where Hilo Bay will be particularly vulnerable to large growths of the seaweed.

Valuable ecosystems along the coasts of all islands are likely to be severely stressed by nutrient-accelerated growth of a variety of algae and seaweeds. The economic damage costs of the resultant degraded ecosystems can be high in resort areas.

Uncertainties in assessing the risks associated with this problem include:

- the time required for injection well discharges to reach the ocean;
- response of various plant species to increased nitrogen, phosphorous, or both;
- seasonality of growth and appearance of the plant matter in recreational areas; and
- relative amounts of nutrients coming from wells and nonpoint sources.

Despite these uncertainties (which are under study), the risk to nearshore, estuaries, and embayment ecosystems and to economic welfare of tourism and recreation is judged to be in the higher category for government attention.

ALIEN SPECIES AS STRESSORS

The recent report, "Hawaii's Extinction Crisis," prepared by the state Department of Land and Natural Resources, the U.S. Fish and Wildlife Service, and The Nature Conservancy of Hawaii, explains the risk from alien or nonnative species:

> The main threat to Hawaii's surviving [terrestrial] native species and natural communities is the destructive effect of non-native species introduced to the islands by people. Hawaii's native species evolved on islands without large mammals. Hence many native species cannot withstand the effects of pigs, goats, cattle, and deer, whose browsing, rooting, and trampling destroys vegetation, accelerates erosion, and opens the way for other animal and plant pests. Today, these hoofed animals have invaded all but a few mountain peaks on Molokai, Maui, and Kauai. Native birds have been hit hard by diseases carried to Hawaii by non-native birds. **Avian malaria** and pox are transmitted to the native birds by mosquitoes, and other introduced pests which have spread into the forest.
>
> Some plants brought to Hawaii by humans have exploded in an environment lacking the natural controls that kept them in check in their homeland. For example, banana poka, an attractive passion flower vine, is limited in its native South America by insects that feed on it. But in Hawaii, banana poka **has already smothered over 70,000 acres of native forest** on two islands and threatens to destroy even larger areas unless effective controls are found. Species that pose even greater threats are poised to invade Hawaii. For example, **on Guam the brown tree snake has wiped out 9 of the 11 species** of native forest birds since 1975. This snake has stowed away on flights from Guam to Hawaii. It has been found here by inspectors on six occasions. But how many times has it not been intercepted? If it establishes itself here, the outlook for protecting Hawaii's native birds will worsen dramatically . . . each year Hawaii is invaded by at least 12 new non-native species. As many as 35 new, non-native species have been known to invade Hawaii in a single year. Among these are species destructive to forests, agriculture, and human health. Without strong, effective inspection and enforcement programs, there will be more destructive and costly invasions.

Although most established introductions and severe impacts have concentrated on terrestrial ecosystems, marine ecosystems in Hawaii are not immune to damage from alien species. Aside from the red alga Eucheuma described earlier, other alien seaweeds have been introduced to Hawaii, causing largely undocumented impacts. In addition, several species of reef fishes and mangroves were intentionally introduced to Hawaii over the past century. Some marine biologists believe that the alien fish species may have displaced indigenous species. There is no question that mangroves have displaced many aquatic and marine species in Hawaii and have encroached on wetland and reef flat habitats important to endemic (and endangered) waterbirds and indigenous reef life.

SOIL EROSION AND SEDIMENTATION AS STRESSORS

Erosion is a natural process in which rainwater detaches and moves soil particles. The amount of soil lost depends on rainfall intensity, soil properties, slope, and protective features, particularly vegetation. The extent and type of vegetative cover is the variable most affected by human activity. Bare soil can be eroded at a rate 10 times that of a pineapple field, 100 times that of a grass pasture, or 1,000 times that of a natural forest. Thus, disturbance by the rooting of wild pigs, overgrazing, or construction activities can greatly increase the rate of soil erosion. Damage at the site of erosion includes destruction of native vegetation, loss of habitat, loss of esthetics, and loss of agricultural or forest productivity.

Further damage occurs when the eroded sediment is transported to streams and eventually to the ocean. The sediment delivery depends on the slope, watershed size, the proportion of fine-sized particles, and the intensity and frequency of rainstorms that can move temporarily stored sediments. The adverse impacts of delivered sediment include siltation of navigable waterways, requiring frequent dredging; burial of productive soils; water turbidity, affecting fisheries and recreation; and smothering of bottom and reef ecosystems. Sediment also often carries toxic chemicals adsorbed on the particles.

Examples of severe sedimentation in Hawaii include Waialua-Haleiwa and Pearl Harbor on Oahu, Kaunakakai and Halawa on Molokai, the Hamakua coast on Hawaii, Manele on Lanai, and Maalaea on Maui. So-called "red days" of nearshore ocean turbidity occur after every rainstorm on agricultural and development land, such as the Kaanapali coast on Maui and leeward Oahu.

Figure 2-2 shows where high rainfall in Hawaii increases the likelihood of soil erosion and sediment delivery.

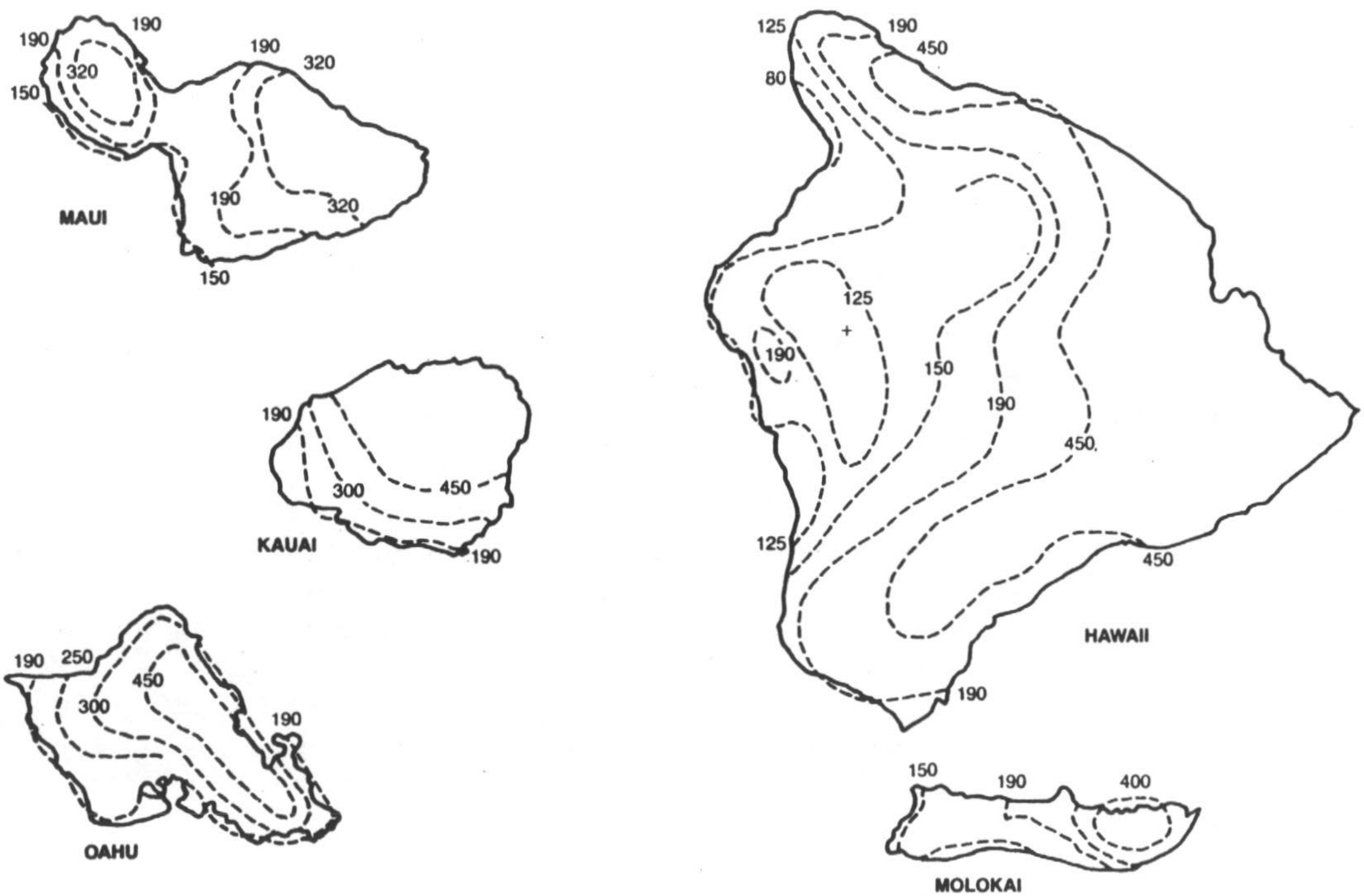

Figure 2-2. Rainfall erosivity maps of five islands of the state of Hawaii, USA (Source: Wischmeier and Smith 1978).

GLOBAL WARMING AS A STRESSOR

The probability is high that the average temperature of the earth's atmosphere will rise significantly by the middle of the next century. There is great uncertainty, however, as to the consequences for the ocean, weather, and climate in any particular locality, especially tropical islands. One consequence important to Hawaii would be sea-level rise due to the thermal expansion of the global oceans. Shorelines would change and some ecosystem occurrences would be replaced by others or shifted landward. Global warming may increase the frequency and severity of hurricanes. The rate of sea level rise will be slow, so that adaptation of some plants and animals may take place, especially where there is no existing urban encroachment on shoreline areas. Here the ecological integrity of the Hawaiian islands may continue. Some of the atolls and shoals of the northwest Hawaiian islands (outside of the HERR project area) may be inundated, affecting nesting habitat for birds, sea turtles, and seals. Eventually coral reef growth might catch up to the rise in sea level, but not without temporary periods of heavier wave action along shorelines and possible island erosion. Direct health risks to Hawaii's citizens are not expected.

The long time likely before consequences of global warming would be substantial here and the uncertainty as to what they would be preclude assessing and ranking this risk. There are reasons for state government action now to (1) continue efforts to conserve energy that are otherwise well-justified on economic grounds and (2) promote long-range planning and development away from shoreline areas.

Regardless of the timing of sea-level rise, a long-term policy for gradual relocation and future location of housing and other damageable structures away from low-lying coastal areas would have the following benefits:

- enhance the quality of life
- provide public access to desirable areas
- increase coastal parks and open space
- reduce future damage costs from storms

- reduce future coastal fortification costs
- reduce property at risk to inundations, and
- lessen the overall socioeconomic effects of sea-level rise.

A gradual increase in the shoreline setback distance and strengthening of existing ordinances and laws are appropriate first steps in developing a long-term shoreline management program for Hawaii that is responsive to future global climate change impacts in urban or built-up areas.

In nonurban areas, it may be important to establish buffer zones to prevent urban development landward of important low-lying coastal ecosystems. This measure would allow ecosystems to adjust naturally, by moving upslope as sea level rises and shifts the shoreline landward. Otherwise coral reef, wetland, estuarine, and coastal ecosystems will be placed at risk along coastal stretches where urban growth occurs directly landward and upslope of these ecosystems. These communities would be more inclined to fortify their urban structures (and their investments) rather than relocate. The net consequence would be the incremental loss or degradation of the ecosystems as sea level rises.

Clearly, there is an immediate need for a comprehensive statewide policy and plan for future shoreline management that covers all shorelines currently occupied or capable of being occupied by people and communities.

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PART 3

RISKS TO ECONOMIC WELFARE

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PART 3

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No.

INTRODUCTION

Ecosystems have economic value because people derive utility from their use or their existence. A healthy ecosystem generates market values by providing goods and services and provides nonmarket values such as air, soil and water quality, flood protection, biological diversity, recreational and educational opportunities, esthetics, and quality of life. Although some of these economic values are nonmonetary, they are important. Pollution, resource extraction, overuse, and alien species invasion can degrade an ecosystem and reduce its economic value. This section discusses the findings of previous work in environmental valuation, reviews some common economic valuation techniques, and, through a series of case studies, examines economic welfare risks of environmental degradation in Hawaii.

LITERATURE REVIEW

International concern for the health of the global environment has been growing. Because of this, much of the environmental economics literature has focused on tropical forests and fragile island and marine ecosystems in Central and South America. A large part of this literature has used market values for timber and nontimber forest products, particularly foods and medicines, to quantify the values and damages to existing ecosystems (Robinson and Redford 1991, Levin 1991, Peters et al. 1989, Myers 1984). Analyses of larger services provided by the environment on a global or local scale, such as soil erosion prevention, watershed protection, climate regulation, flood protection, are far less developed. Some of this work is presented below; however, valuation methodologies continue to evolve along with our understanding of the complexity of each ecosystem we study.

Recent work in economic welfare risk and environmental degradation has indicated the importance of conserving biodiversity by "demonstrating in economic terms the contribution biological resources make to the country's social and economic development [and loss to society when damaged]" (McNeely et al. 1990:11, Wilson 1988, Norton

1986). Prescott-Allen and Prescott-Allen (1986) and Pearce (1987) demonstrate how the dollar value of biological resources might be estimated using actual, option, and existence values. Sherman and Dixon (1989) discuss the economics of protected areas under this comprehensive format. Existence values have been separated into national and international existence values by Thomas et al. (1991), indicating changes in resource values at country and global levels and emphasizing the global impact of site-specific damages.

Dixon and Hufschmidt (1986) illustrate the use of benefit-cost analysis and other techniques in a number of case studies, including assessment of water resources and watershed protection, and lake and marine bay fisheries projects. Poulos (1975), Drigot and Seto (1982), and Hair (1988) look at the annual cost savings of flood protection by maintaining a wetlands complex. Educational and research values of ecosystems have been explored by examining research expenditures (MacDonald and LaBarge 1990), estimating visitor numbers, and measuring students' learning from site visits (Fortner 1990).

Powers (1988) provides a good overview of the values of environmental quality and esthetics. In urban settings these values may be revealed through land and house prices (Grimes 1983, Pollard 1982). Esthetic vistas (Huddleston 1983), clean air views (Freemuth 1991, Shultze et al. 1983), and presence of wilderness or specific flora and fauna (Vickerman 1991, Defenders of Wildlife 1990, Boo 1989) are far more difficult to value and are often discussed in qualitative terms or estimated with existence valuation methods.

Economic studies on environmental quality specifically in tourist destination areas addressed three major issues: (1) the impacts of pollution on tourism-related economic values, (2) environmental degradation caused by tourism, and (3) ecotourism. This literature has been more qualitative than quantitative because of difficulties in valuing the large number of services provided by the natural environment.

The impacts of pollution on tourist areas are well demonstrated in a U.S. Department of Commerce study (1983) of the <u>Amoco Cadiz</u> oil spill in Britanny, France. Due to oiled beaches, major losses in tourist industry revenues and consumer welfare were recorded.

Tourists today are far more environmentally aware (and concerned) than their predecessors and are demanding higher standards of environmental quality. Tour operators now call for boycotts of degraded sites in favor of other destinations, as in the case of Pattaya, Thailand (Bangkok Post/Nation 1988-92), and Penang, Malaysia (Hong 1985). A survey by the Tourist Research Institute in Germany found that 84% of respondents advocated looking elsewhere if a destination's environment was badly harmed, if beaches were dirty, if the countryside was spoiled by traffic, or if forests were dying (Environmental News Digest 1990).

Ecotourism (environmentally conscious tourism to natural areas) is a small but growing sector of the tourism market that is increasing the value of biological diversity, endangered species, and naturally functioning ecosystems. Boo (1989) reviews the progress of ecotourism in the developing world. Vickerman (1991) assesses the value of ecotourism in the United States. Successful ecotourism depends on a high-quality environment; however, tourism development itself may degrade those qualities. The problem of maintaining a balance between tourism and long-term environmental health (the issue of carrying capacity) was documented by the OECD (1980), where environmental deterioration in Majorca, Spain, caused a shift of tourists to other destinations. The dilemma of increasing tourism revenues, rising visitor counts, and environmental stability that allows continued economic benefits presents one of the major issues for future research in economic welfare and environmental risk.

ECONOMIC DAMAGES IN ECOSYSTEMS AND VALUATION METHODS

The literature on economic valuation techniques for environmental degradation is vast. Applied theory is continually evolving. For comprehensive overviews of techniques, the reader is referred to reviews by Cummings et al. (1986) on contingent valuation and comprehensive summaries of techniques by OECD (1989) and Hufschmidt et al. (1983).

The following describes some common methods for valuing ecosystem services. Economic damages represent the monetary valuation of environmental impacts from residual pollution problems. **Direct ecosystem values** include production (e.g., fishery, forestry, agriculture), commercial services, and unpriced amenities. Other values are indirect or involve potential use (option value) or nonuse (existence value) of ecosystems. Where ecosystem damages cannot be valued in monetary terms, damages should be discussed qualitatively.

The primary method for valuing productivity losses from environmental degradation is **change in productivity.** The method calculates the difference in production, valued at market prices, from a natural system with and without degradation. The **resource restoration cost** method calculates actual or predicted expenditures to restore the damaged resource to its former condition.

The **loss in income** method can be used to estimate welfare damages to commercial firms affected by environmental degradation. This method calculates the difference in the net income of commercial enterprises with and without resource degradation.

Hawaii's ecosystems provide a range of environmental amenities, such as recreation and esthetic enjoyment, which are largely unpriced. The most generally applicable method of valuing such amenity losses is **contingent valuation.** This approach involves direct questioning of consumers to ascertain the willingness of individuals to pay for environmental improvements or, alternatively, their demand for compensation for environmental losses.

Travel cost and **property value** are two other methods of estimating amenity values. The travel cost approach utilizes information on differences in travel costs and visitation rates from different communities to estimate a demand curve for a recreation area. The property value method uses multiple regression analysis to estimate how proximity to amenities such as good beaches or urban parks influences surrounding property values.

Indirect ecosystem values often benefit society at large rather than individuals or businesses. For example, the indirect ecosystem values of watershed and wetlands include regulation of freshwater supplies, nutrient cycling, protection of soils, maintenance of atmospheric quality, and climate control. **Option value** measures the willingness of individuals to pay in order to retain the option of having future access to a species or resource. **Existence value** is the value people attach to the existence of species or habitat that they may have no intention of ever using or visiting but get satisfaction in knowing that they exist.

Contingent valuation is a common method economists use to estimate indirect, option, and existence values. **Contingent ranking** is a related approach but provides an ordinal ranking rather than cardinal values.

Many of the valuation methods mentioned have theoretical and practical limitations and require careful interpretation. However, uncertain scientific knowledge about what services ecosystems provide and how ecosystem services are affected by stressors is probably a more serious problem in actually performing economic welfare analysis. This HERR report notes many uncertainties in cause-effect relationships and quantification of impacts. These uncertainties preclude useful economic valuation in many instances of ecosystem degradation from human activities.

CASE STUDIES

This section demonstrates economic methods for assessing environmental risk in Hawaii through a series of case studies. The case studies selected represent a cross-section of ecosystem types, including an embayment-estuary (Pearl Harbor), a sandy beach with bottom shore (Lahaina), oil spill pollution, a barrier reef and embayment (Kaneohe Bay), an embayment with a sandy beach and coral reef (Hanauma Bay), a coastal wetland (Kawai Nui Marsh), and an upland forest (Kula Reserve). The majority of ocean sites reflects the importance of marine ecosystems to Hawaii's tourist industry. The wetlands and forest studies were included to indicate the growing potential of these sites for resident and tourist use and their importance in the overall visual image of Hawaii. These studies examined economic damages from the following types of stressors: sediments, nutrients, freshwater dilution, chemicals, heavy metals, toxics, alien species invasion, fire, and overuse.

A review of previous studies and personal interviews with area experts was conducted to assess these sites. Specific data to assess economic risk were unavailable for all cases. For the Kawai Nui Marsh, Kula Forest Reserve, and oil spill pollution studies, insufficient information was available to quantify the primary economic values. For these cases we have provided a verbal description of the situation backed by relevant statistics and offer suggestions for future work.

PEARL HARBOR, OAHU

The Pearl Harbor estuary has approximately 5,089 acres of wetlands and consists of a main channel and three lochs with eight streams discharging into the harbor. Land uses in the watershed include pineapple and sugarcane agriculture, pasture, forest reserves, and urban and military facilities. Shipping and navigation activities associated with military support constitute the main uses of the harbor. Other uses of Pearl Harbor include two designated areas for endangered Hawaiian waterbirds, a nehu bait fishery, and an oyster habitat. Oysters were introduced in 1870 but have never been commercially harvested due to microbial and bacterial contamination.

Sediment delivery from nonpoint source runoff is the major stressor to ongoing uses in Pearl Harbor. The amount of soil transported to the harbor from the eight streams in the watershed was estimated by the Economic Research Service (1975) to be 96,230 tons per year. Construction activity and agriculture are the major causes of erosion. The welfare damages assessed for Pearl Harbor are (1) damage to navigation from siltation, (2) potential loss of endangered waterbirds from siltation and pesticides, and (3) reduction of the nehu bait fishery due to overfishing and damage to breeding habitat.

The cost of sedimentation is valued as the expected annual cost of dredging to restore the harbor's navigational potential. Using dredging data from the past 20 years, expected future annual dredging costs were estimated to be $1.4 million. The cost of required physical and biological testing of dredge sediments is an additional $200,000 dollars per year. Therefore, a rough estimate of the damage

Table 3-1
Pearl Harbor: Potential Benefits and Costs from Sediment Control

	Costs	Benefits
Downstream control	Dredging-related costs ($1.6 million/yr)	Improved navigation
	Maintaining wildlife refuges ($0.1 million/yr)	Protection of endangered waterbirds
Upstream control	Improving soil conservation practices in agriculture	Reduced dredging costs (up to $1.6 million/yr)
	Implementing more stringent construction standards to reduce soil loss	Improved habitat for waterfowl and fish
	Constructing sediment basins	Improved agricultural productivity

costs of sedimentation is $1.6 million per year. Technically, this amount could be spent upstream to reduce erosion in the watershed, the primary source of the sediment. Soil retention could also benefit upstream agriculture.

Nutrient loading from leaky cesspools and agriculture runoff have negative effects on water quality, marine life, and water bird habitat. To protect endangered waterbirds in Pearl Harbor, two wildlife preserves are maintained and staffed at a cost of approximately $100,000 per year.

The nehu bait fishery in Pearl Harbor was valued at $962,056 per year. The harbor was heavily fished during the 1970s. After closure of the tuna cannery, catch levels declined so that overfishing is no longer a problem. The potential of the oyster fishery has not been assessed in this study. A list of the potential benefits and costs from soil erosion control in Pearl Harbor appears in Table 3-1.

As a result of soil erosion and sedimentation in Pearl Harbor, an estimated $1.7 million is required to maintain navigation and preserve the endangered Hawaiian bird habitat. The nehu bait fishery is protected through restricted access by the State Division of Aquatic Resources and the U. S. Navy and is not at risk. Overall, it appears that resource users of Pearl Harbor have addressed these issues and have taken necessary actions to abate ecosystem threats. The potential for upstream monitoring and management control should be investigated, as sediments from construction and pesticide from agriculture continue to threaten the resources at Pearl Harbor.

LAHAINA, WEST MAUI

West Maui is a major tourist destination and includes the town of Lahaina and the Kaanapali and Napili coastlines. Commercial offshore ocean recreation activities include skindiving, scuba diving, and whale watching. Fishing, tako and limu nearshore reef collecting, surfing, windsurfing, kayaking, and gillnetting are common noncommercial activities on the inshore reef. Sunbathing, swimming, and picnicking are popular activities at all beach locations.

Sedimentation from floods has caused considerable damage to the beaches and fringing reef in the past. Since floodwater diversion channels were installed in 1990, sedimentation is no longer a problem (Soil Conservation Service 1990). Residual sediments from previous floods occasionally cloud the waters.

Algae blooms are the major concern of hotel and ocean recreation industries. Cladophora, a long filamentous algae, has spread over the inshore reefs and reef slopes in West Maui. It has caused damage to coral, reduction in water clarity, subsequent losses to recreational activities for dive and submarine tour operators, and has required beach cleanup by hotels. The primary pollutant source contributing to algae growth is believed to be effluent discharge from injection wells at the Lahaina Wastewater Treatment Plant. Other likely pollution sources are sewage discharge from boats, agricultural runoff, and soil erosion from coastal construction.

Revenue losses to the commercial recreation industry have been attributed to the algae problem. Damages include losses in commercial recreation earnings and reduced visitor and resident satisfaction from recreational activity. Dive shop owners are claiming losses in business and future losses from fewer repeat visitors. While many diving operations take their customers to Molokini and Lanai, the deteriorating quality of nearshore environments could lead to short-

Table 3-2
Costs and Benefits of Controlling Cladophora Blooms

Costs	Benefits
Controlling effluent discharges from the wastewater treatment plant	Improved water quality
	Increased hotel earnings
Identifying and controlling other effluent sources	Increased earnings of commercial dive companies
	Improved quality of recreational use

and long-term losses in commercial revenues. The Cladophora problem is serious because it is most prominent during the summer tourist season. A list of the potential benefits and costs from controlling the Cladophora problem in West Maui appears in Table 3-2.

The Cladophora blooms affect all ocean recreation industries dependent on tourism in West Maui. West Maui visitors spent approximately $9.9 million per year on diving and whale-watching activities (Hawaii Department of Business, Economic Development and Tourism 1990). In West Maui, 28% of the ocean recreation industry's annual revenues are generated during the months of June through August, when Cladophora blooms are worst. According to local tour operators, 60% of repeat business is lost due to algal blooms, implying that 1991 losses were approximately $840,000.

Losses to other tourist-related industries, such as hotels and restaurants, and to the resident population requires further study. Recurring and potentially worsening algae problems would cause more visitors to seek alternate sites for diving and whale-watching activities.

KANEOHE BAY, OAHU

Kaneohe Bay supports commercial, recreational, subsistence, and nehu bait fisheries. Commercial fishing includes both food and aquarium species. A wide variety of other commercial and noncommercial recreational activities occur in the bay, including sailboating, motorboating, scuba diving, snorkeling, windsurfing, waterskiing, canoeing and kayaking, and body surfing. Other uses of the bay include camping, picnicking, and conducting research. It provides an esthetic benefit for nearby residents.

The draft Kaneohe Bay Master Plan (Hawaii Office of State Planning 1992) identifies the following pollution sources: sewage leaks, seepage, and occasional bypasses; cesspools, landfills, and waste disposal sites; nutrients from agriculture, golf courses, and urban yards; stormwater runoff; sewage discharge from vessels; sediments from excessive freshwater inflows; thermal pollution; and toxic discharges. High nutrient levels promote algae growth, which can negatively affect the growth of fish, coral, and other organisms by reducing available light, oxygen, and food.

A recent economic evaluation of the Kaneohe Bay Master Plan (Loudat et al. 1992) provides the supporting data for valuing damages to the bay from various stressors and the benefits and costs of improvements. The damage estimates are the difference in use values from a management scenario that achieves "minimal impact" on the bay and a "no-action" scenario that allows the trend in present activities to continue. Changes in real estate values are not reported here.

The estimated annual damage to fish and baitfish is $0.5 million per year. The annual loss in noncommercial recreation values due to reduced water and coral quality is estimated at $4.5 million per year at current use levels but is expected to be $13.1 million per year with less restricted access to the bay provided by implementation of the Master Plan. These noncommercial recreation values should be interpreted as order-of-magnitude estimates because information on how bay users value improved bay quality was not available.

The "minimal-impact" scenario was considered too restrictive by the Task Force because lost income from tightly restricted commercial recreation values would far exceed the resulting increased value of the fisheries. The recommended plan allows greater commercial recreation with a resulting lower value of the fisheries. The costs of the recommended plan include implementation actions ($3.3 million per year) and a lower level of commercial activity ($0.8 million per

Table 3-3
Costs and Benefits of Kaneohe Bay Master Plan Scenario

	Costs	Benefits
No action	Reduced fishery ($0.5 million/yr)	
	Degraded noncommercial recreation ($4.5 million/yr)	
Master Plan (annualized over 20 yrs)	Plan implementation ($3.3 million/yr)	Increased fishery ($0.2 million/yr)
	Reduced commercial recreation ($0.8 million/yr)	Enhanced noncommercial recreation ($13.1 million/yr)

year) than under the "no-action" scenario. The benefits occur primarily from increased quantity and quality of noncommercial recreation and improved fisheries (Table 3-3).

HANAUMA BAY, OAHU

In 1970 Hanauma Bay was designated a Marine Life Conservation District and an Underwater State Park. Because of the presence of colorful marine life and warm, clear waters, the bay is a popular site for snorkeling, scuba diving, sun bathing, and sightseeing. In 1989, 2.7 million tourists (over 50% of all tourists on the island of Oahu) visited Hanauma Bay. For the $11 billion tourist industry, Hanauma Bay is one of the state's most important natural attractions. Because it is a unique coral ecosystem, Hanauma Bay also offers scientific and research opportunities.

The major stressors to Hanauma Bay are pollution and overcrowding. Water at Hanauma Bay is polluted by sewage leaks, fish food, litter, fresh water from showers, and suntan oil. These pollutants reduce water clarity, degrade water quality, and inhibit coral productivity. In 1989, as many as 10,000 people visited the bay in a single day, severely taxing the physical and biological resources of the bay. Due to overcrowding and overuse, pollution levels in the bay rose. In the highly trafficked areas of the bay, much of the coral was trampled by inexperienced snorkelers or smothered from bottom sediments stirred up by the numerous waders. Because of continuous heavy use, the coral was severely degraded.

Many Oahu residents simply stopped going to the bay because of the crowds. In 1989 only 6% of the total visitors to Hanauma Bay were Oahu residents. To reduce crowding, in 1990 the state restricted visitor numbers and reduced park hours. As a result, total visitor numbers were reduced by 32% and resident numbers increased by 37%. These findings are summarized in Table 3-4.

To improve the quality of the park environment, the septic system was replaced, a visitor information program on the reef ecosystem was implemented, and the number of visitors using the park at one time and total visiting hours were reduced. Plans to construct a visitor information center are in progress. The costs and benefits of recent management decisions are listed in Table 3-5.

Much of the risk to Hanauma Bay stems from the fact that little is known about the biology of the bay environment and its capacity for long-term use. To aid future managerial decisions, a recent study (Lee and Gallagher 1992) modeled the influence of alternate management policies on the reef ecosystem. The model results reflected expert opinion. Current actions and use restrictions will improve water quality and help to slow, but not halt, the degradation of the coral reef. Without further action, the coral ecosystem will continue to be degraded from overuse. To sustain the quality of the bay for future use, stronger actions and more stringent or innovative use restrictions will likely be required.

OIL SPILL POLLUTION RISK

Due to the large volume of shipping traffic and the state's dependence on external sources of oil, Hawaii's economy is particularly vulnerable to offshore oil spills. Ocean vessel collisions, groundings, and accidental leaks spill thousands of gallons of oil into the ocean each year. Between 1987 and 1991, a total of 250 oil spills in Hawaiian coastal waters, ranging in size

Table 3-4

Annual Visitor Numbers at Hanauma Bay
Before and After 1990 Restrictions

Visitor Type	1989	1991	% Change
Tourists	2,686,000	1,719,000	-36
Residents	171,000	234,000	+37
Total	2,857,000	1,953,000	-32

Table 3-5

Hanauma Bay: Costs and Benefits of Recent Management Decisions

	Costs	Benefits
Switch over to municipal sewer system	$140,000/yr* in amortized fixed costs plus maintenance and service cost	Reduced cost of annual septic system pumping ($4,000/yr)
	Improved water quality	
Entrance and use restrictions	Security and traffic control	Increased quality of visitor experience
	Enforcement of off-site parking restrictions ($93,000/yr)	Increased usage by residents
		Some coral recruitment
	Lost tour bus revenues ($7.35 million in 1991)	
	Lost recreational use (904,000 fewer visits in 1991)	
Education	Visitor information program ($192,800)	Reduced coral destruction from wading, trampling, and fish feeding
	Visitor information center ($850,000 construction costs)	

*Assumes a 5% discount rate and 20-year amortization.

from 1 gallon to 120,000 gallons, were reported to the U.S. Coast Guard. Small spills have already been identified as a source of marine pollution that requires attention.

The economic welfare risk to Hawaii of a large oil spill is a function of the cost of a large spill and its probability of occurrence. A large offshore oil spill the magnitude of the Exxon Valdez spill (10.8 million gallons) could seriously disrupt fragile marine ecosystems and devastate the entire state economy. Total spill costs would include at-sea response, spill cleanup, waste oil disposal, vessel damage, lost visitor revenues, and environmental damages and restoration. Some of these costs were estimated in a recent Sea Grant study for the Department of Health (Davidson and Olive 1992, Lee et al. 1992). The probability of a spill the magnitude of the Exxon Valdez occurring in Hawaii is about 0.74%, or once in 135 years. An offshore spill between 10,000 and 20,000 gallons occurs about once every two years, and a spill between 40,000 and 50,000 gallons takes place every 4.5 years (Lee 1992). To date, the cleanup costs and economic damages from these medium-sized spills have not been well documented. Additional work on estimating the probability of future spills and the costs expected to be incurred could help determine whether additional investment in spill response and prevention is economically warranted. A list of the potential benefits and costs from oil spill response and prevention appears in Table 3-6.

The current oil spill response capability of the U.S. Coast Guard in Hawaii is 42,000 gallons. The state has no spill prevention plan. Given Hawaii's unique marine ecosystems and economic dependence on its image of clear blue waters and clean sandy beaches, adoption of state standards more stringent than those required by federal law may be economically warranted. Additional work in this area merits further attention.

KAWAI NUI MARSH, OAHU

Kawai Nui Marsh, located at the base of the Koolau mountains in Kailua, is the largest deep, freshwater marsh in the state, covering

Table 3-6
Oil Spill Pollution: Benefits and Costs of Protection

	Costs	Benefits
Increased spill response capability	Equipment, materials, training, and labor costs	Reduced offshore/shoreline damages Reduced response and cleanup costs, shoreline damages, habitat loss, and oiling of marine life Reduced loss of recreational uses, tourist revenues, and commercial fishing days
Oil spill prevention	Implementation, monitoring, and enforcement costs	Reduced risk of spills Reduced likelihood of high cost, potentially irreversible environmental damages from some spills

approximately 1,000 acres. Three streams from the surrounding basin feed into the marsh. Two major channels connect the marsh to Kailua Bay. Native aquatic vegetation has been substantially replaced by California grass and water hyacinth.

The two major uses of the marsh are flood prevention and as an endangered wildlife habitat. Four endangered species of waterbirds inhabit the marsh on a permanent basis: the Hawaiian coot, Hawaiian duck, Hawaiian stilt, and Hawaiian gallinule. The marsh is considered "critical habitat" for these birds due to limited coastal wetland areas remaining in Hawaii (King et al. 1989). The marsh is also used for environmental and cultural education and research, for recreational activities such as walking, jogging, fishing, birdwatching, and for its esthetic vistas for the surrounding community. A number of Hawaiian historical sites are found in and around the marsh, including Ulupo and Pahukini Heiau. The marsh also recharges the underlying groundwater aquifer (Kawai Nui Marsh TPAM 1983).

Sediments and nutrients (from storm runoff, stream bank erosion, agricultural activities, construction scars, and quarry runoff), dirt and debris from urban runoff sources, and rapid vegetation growth induced by excess nutrients reduce the marsh's flood protection capacity and disrupt wildlife habitat. Other stressors to the marsh include heavy metals and bacterial contamination (attributed to cattle grazing around the marsh). The combined effect of these stressors has been to shorten the marsh's viable lifespan as a wetland. Quality habitat and preferred food sources for endangered waterbirds have been degraded. The quality of esthetic, recreational, and educational use opportunities, and the marsh's effectiveness as a flood control, water filter, and aquifer recharge source have also diminished (Kawai Nui Marsh TPAM 1983).

Economic welfare losses from flooding due to sedimentation and vegetation overgrowth are significant. Flood damage to Kailua in 1987 was estimated to be $10 million (M&E Pacific 1990). The probability of a flood of this magnitude reoccurring in any given year is slightly less than 1%. For the future, average annual residual flood damages are estimated by the Army Corps of Engineers to be $1.9 million (Pennaz 1992).

The current recommended plan for flood control includes a factor of safety that would preclude any residual flooding from occurring and will reduce flood damage from $1.9 million to zero annually (Pennaz 1992). The cost of this plan, which includes mitigation activities, land acquisition, and past studies, is $10.4 million. Annual maintenance costs, including vegetation control, would be $98,300. However, downstream mitigation addresses only a few functions and problems of the marsh.

Upstream measures to control sediment and nutrient runoff have not been assessed, but might lower annual maintenance costs for vegetation control and dredging, as well as improve health of the entire wetlands ecosystem and its natural functions. With upstream control, the option and existence values of the marsh would also be retained. The combined measures would likely extend the life of the marsh. The categories of costs and benefits of downstream and upstream controls are listed in Table 3-7.

Much of the risk of flooding in the marsh stems from upstream sources, but mitigation has been directed solely at downstream flood control. Research is needed on the costs of upstream sediment and

Table 3-7

Costs and Benefits of Downstream and Upstream Actions for Kawai Nui Marsh

	Costs	Benefits
Downstream (flood control)	Flood damage mitigation (projected cost $10.4 million)	Decreased risk of floods, increased flow of water
	Annual maintenance costs (projected cost $98,300)	Annual residual flood damage reduced to zero
	Damages from maintenance measures (e.g., residual chemicals from plant control and dredging)	Enhanced bird and fish-breeding habitat from more open waterways
	Reduced effectiveness of natural filtering mechanism of marsh due to increased water flows	Improved actual and option values for recreation, education, and esthetics
Upstream (sediment and nutrient source control)	Mitigation measures to reduce runoff, including education of residents to do so	Reduced sediments, nutrients, and plant growth throughout marsh; improved health and longevity of wildlife habitat
	Monitoring and enforcement costs	Reduced annual in-marsh maintenance costs and reduced damages from maintenance measures
		Improved quality and value of recreational and educational experiences and esthetics of the marsh
		Improved existence and option values of the marsh as a complete ecosystem
		Improved upstream agricultural soil productivity
		Improved stream quality
		Greater environmental accountability from upstream users and improved quality of life for residents and users of the marsh

nutrient source control over the long term in order to judge the cost-effectiveness of such measures compared to on-site flood control. Studies that quantify the effects of residual chemicals on bird and fish populations, current educational and recreational uses of the marsh, and esthetic benefits of the marsh to the residential community will provide more specific damages and value estimates. The potential of Kawai Nui as an historical, recreational, and educational site similar to Heeia State Park merits further study.

KULA FOREST RESERVE, MAUI

Kula Forest Reserve on Maui is located above Waiohuli homestead lands, west-southwest of Haleakala Crater, at an elevation of 5,300 to 9,000 feet. The reserve contains 5,938 acres of native species, including koa, ohi'a, mamani, pukiawe, ohelo, sandalwood, and introduced species, including mature stands of redwood, eucalyptus, and a number of conifers (Wong 1992). Polipoli Spring, in the southern corner of the reserve, is the sole major water source and provides water for a forestry cabin and two ranches located below the reserve.

The primary functions of the reserve are as watershed protection and conservation land for native flora and fauna. It is home to two endangered Hawaiian bird species, the apapane and the amakihi. An increasing number of people use the area for outdoor recreational activities, including hunting, hiking, picnicking, camping, and biking.

Primary stressors to the reserve are alien plant and animal species and fires. Alien plant species include black wattle, firebush, raspberry-type species, and grasses. Feral pigs are responsible for some soil and plant disturbance. Fires are entirely manmade. Fires increase the opportunity for encroachment by alien plant species. The risk of fire and alien species invasion increases with recreational use. Fire and alien plant and animal species increase soil erodibility and raise the maintenance costs of watershed and native species habitat protection since they require continual surveillance and management.

Fire-related welfare damages include fire suppression costs and losses from fire. Fires in the Kula Reserve have burned a total of 210 acres since 1977, or an average of 14 acres per year. U.S. Forest Service fire damage values range from a maximum $5,100 per acre (in 1991 dollars) for commercial timber and rare and endangered wildlife habitat to a minimum of $340 per acre for general wildlife habitat (Costales 1992). Actual fire damages under present conditions, thus estimated, are between $5,000 and $71,000 per year. Fire suppression costs vary depending on location and agencies involved. For example, a fire in Mopua, Maui, in 1991 burned 683 acres in a state forest reserve. Suppression costs were $88,000. Fire suppression and fire damage figures do not include long-term restoration costs of burned areas or loss of native tree species and genetic seed stock (and subsequent impacts on endemic birds in the reserve. To reduce fire risk, park managers periodically close the reserve to all users during the dry season, causing a decline in recreational values as well. Reduction of annual fire damage to zero is unlikely even if all recreational and educational activities within the reserve were eliminated.

Alien species have affected 10% of the reserve. Eradication costs specific to Kula reserve were not available. The Banana Poka Eradication Program for the entire island of Maui has been allotted $100,000 by the state for two years (1991-93). The actual costs of this and other eradication programs are largely underestimated due to their use of volunteer labor. Feral pig populations are primarily controlled by allowing recreational hunting in the reserve. A list of benefits and costs of protecting the Kula Forest Reserve appears in Table 3-8.

Efforts to protect Kula Forest from fire damage have been largely effective. Invasion by alien plant species is a significant problem only in some parts of the reserve. Environmental risks will likely increase as the demand for upland recreation and Kula resources grows. More information is needed on the value of Kula Forest and other Hawaii-specific upland forest sites to determine whether additional fire protection, habitat maintenance, and alien species control is warranted. Improved tracking of expenditures for fire prevention,

Table 3-8
Costs and Benefits of Protecting the Kula Forest Reserve

	Costs	Benefits
Fire protection	Fire suppression Monitoring, education, and fire prevention Lost recreational opportunities due to closure for fire risk protection Restoration costs for land to return to original state	Reduced risk of loss or damage to entire forest by fire and alien species invasion Less erosion and surface water runoff, greater groundwater recharge Reduced cost of eradication of undesirable alien species due to fewer opportunities for invasion Greater protection for indigenous flora and fauna
Alien species control	Eradication, maintenance, and monitoring of alien species growth Restoration costs of establishing native species	Increased value of recreational, educational, and esthetic experiences and values Increased option and existence values
Feral pig control	Monitoring Administrative costs of permit process, management of hunters in the reserve Increased risk of fire due to presence of hunters off trail and camping, some ecosystem disturbance from tracking	Revenues from hunting permits Recreational and meat value to hunters, quality sporting experience Reduced soil and native plant ecosystem, disturbance from pigs

suppression, and restoration, and alien species eradication would provide more accurate damage costs. The increasing value of forests in Hawaii as recreational and educational sites for residents and visitors indicates the need for a more in-depth assessment in order to maintain the health of forest reserves for future use.

PRESS REPORTING ON ENVIRONMENTAL DEGRADATION

An image of high-quality natural environments is what sells Hawaii as a tourist destination. Media coverage can influence a tourist destination's image, which can be tarnished by frequent negative articles implying a deteriorating environment. For example, negative press articles significantly reduced visitor arrivals in Jamaica (Cuthbert and Sparkes 1978). In Thailand, Malaysia, Belize, and other tourist destinations, press articles on environmental degradation have already influenced tourists' impressions and have caused visitors to choose other destinations.

While advertising campaigns can sometimes counter negative press coverage of short-term, recoverable events such as oil or sewage spills, they are less effective in reversing the damage from the perception that the quality of a tourist destination is in decline. Empirically, this is difficult to measure because the relationship between negative press coverage and visitation levels often cannot be statistically separated from economic conditions, exchange rate fluctuations, and other factors influencing tourism demands for a destination. However, the knowledge that environmental issues appear in the media might help to determine if a destination is being threatened by environmental neglect.

To this end, five national newspapers were surveyed to assess their coverage of environmental degradation issues in Hawaii between 1989 and 1991. During this time 31 articles appeared. Twenty-four of the articles discussed negative environmental situations, three discussed positive situations, and four presented neither. The major environmental issues were oil spills, geothermal electricity development impacts, and Hawaii's endangered species. Local newspapers produced 656 articles on these issues during the same period. While there were not many newspaper articles, the national press is reporting on perceived short-term and long-term environmental threats.

The study on press articles pointed out a need for research focusing on the relationship between tour operators, their impressions of a tourist destination (based on press articles and customers returning from a vacation destination), and the recommendations they are making to potential visitors on the mainland. A study of the geothermal development protests in 1989 is of interest because adverse publicity directed toward potential visitors to Hawaii became a means of protest (Hannah 1990). A more systematic monitoring of press articles is also needed. Further study of press reporting on environmental degradation, tourism promotion campaigns, and promotion expenditures in similar coastal tourist sites would be useful in clarifying the links between environmental degradation, the media, and the source of potential visitors' impressions.

FINAL REMARKS

This study examined the risks to economic welfare of environmental degradation in Pearl Harbor, Lahaina, Kaneohe Bay, Kawai Nui Marsh, and Kula Forest and due to oil spill pollution. These case studies were selected to demonstrate the application of economic methods in environmental risk assessment. We found good general information on coral reef ecosystems, estuaries, mangroves, sandy beaches, marshes, and forests, and the environmental problems that have surfaced in Hawaii and may arise in the near future.

Although only a handful of sites in Hawaii were examined, environmental degradation poses an economic welfare risk to many more. Identifying the sites meriting priority attention will require careful study. Fortunately, indicators for the majority of sites at greatest risk are evident. This study suggests that future work focus on locations that offer high quality recreational use, comprise an environment that is locally or globally unique, provide a distinct beneficial service, or are heavily used in commercial operations. Attention should be given to sites that are either at risk of becoming degraded or are already suffering environmental stress. Key indicators of stress are evidence of external sources of pollution, heavy overuse, misuse, and multiple uses with apparent conflicts in use. Observed reduced use of a site and documentation of declining commercial revenues from a site can indicate areas with problems due to environmental degradation.

Technological, regulatory, and economic means exist to control or reverse the process of environmental degradation. Sometimes, however, directly addressing a problem with onsite means of control will correct the original problem while inadvertently creating another. Studies that ignore these newly created problems will underestimate the true social cost of control. Controlling the problem at its source, while sometimes more costly, may compare favorably to onsite mitigation measures when the additional offsite and long-run benefits (such as ecosystem preservation and resource sustainability) are counted. Prudence thus suggests that in the face of environmental degradation, planners consider a wide range of mitigation alternatives and broadly evaluate the scope of both the positive and negative environmental effects.

The case studies examined in this paper were among those receiving the most attention in recent years. The data required to complete an empirical welfare analysis were nonetheless severely lacking. We expect future work in economic welfare analysis to be similarly hindered. This study suggests development of site-specific quantitative measurements of environmental quality, recreational activity, endangered animal and plant species, and commercial use. Also needed are statewide studies to monitor tourist and resident perceptions of environmental degradation. A database of this scope would enable comprehensive coverage of the economic value of ecosystems in Hawaii and the losses that could be expected from continued degradation.

Due to the heavy dependence on tourism for revenue and employment, the long-term high quality of Hawaii's environment is critical to the vitality of the state economy. Estimates of the economic welfare values associated with environmental degradation can be used to formulate policy and evaluate the policy alternatives needed to alleviate damages and to protect the environment for future generations.

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